PROCEEDINGS **COMPTES-RENDUS**

GASReP PRESSC /DESRT

2nd Annual
Symposium on Groundwater and Soil Remediation

2e Symposium annuel
sur la restauration des eaux souterraines et des sois contaminés

Sponsored by

Members of GASReP

Environment Canada - DESRT

British Columbia Water and Waste Association

March 25 and 26, 1992
Vancouver, British Columbia

25 et 26 mars 1992
Vancouver (British Columbia)

Final Program

GASReP/DESRT

2^{nd} Annual Symposium on

Groundwater and Soil Remediation

Sponsored by

Members of GASReP

Environment Canada - DESRT

British Columbia Water and Waste Association

March 25 and 26, 1992

Hotel Vancouver
Vancouver, British Columbia

92-04404/

SYMPOSIUM PROGRAM

March 25, 1992 Day 1

07:30-08:30 Registration

SESSION 1 RESEARCH PROGRAMS ON GROUNDWATER AND SOIL REMEDIATION

Session Chairperson - Alex Lye, Environment Canada, Burlington, Ontario

08:30-08:45 **Welcome/Opening Remarks** - Alex Lye, Environment Canada, Burlington Environmental Technology Office, Burlington, Ontario

08:45-09:05 **Keynote Speaker** - Barry Olsen, Ministry of Environment, Lands and Parks, Vancouver, British Columbia

09:05-09:25 **Update on the national Groundwater and Soil Remediation Program (GASReP)** - Alex Lye, Environment Canada, Burlington Environmental Technology Office, Burlington, Ontario

09:25-09:40 **Overview of the Development and Demonstration of Site Remediation Technologies (DESRT) Program** - George Hill, Environment Canada, Technology Development Branch, Hull, Quebec

09:40-10:00 **Research Activities of the Groundwater and Soil Task Force of the Canadian Petroleum Products Institute (CPPI)** - Adolfo Silva (CPPI), Petro-Canada Inc., Calgary, Alberta

10:00-10:30 Coffee Break

10:30:11:00 **Canadian Petroleum Association (CPA) Environmental Research Advisory Council - Overview of Research Activities** - George Collin (CPA), Amoco Canada Petroleum Company Ltd., Calgary, Alberta

11:00-1 :30 **Overview of Soil and Groundwater Research of the American Petroleum Institute (API)** - Dr. Bruce Bauman, American Petroleum Institute, Washington, DC

11:30-12:00 **R, D & D Needs and Priorities for the DESRT Program** - Brian Whiffin, CH2M HILL Engineering Ltd., Waterloo, Ontario

12:00-13:30 Lunch

Symposium Program

The program will focus on research activities of GASReP and some of its members, and DESRT. Some papers will provide overviews of several research programs on innovative technologies, while others will present findings of research projects under GASReP, DESRT, and other programs. Also, about fifteen selected vendors will present technical posters on their remediation technologies.

March 25, 1992 Day 1

SESSION 2 BIOREMEDIATION

Session Chairperson - Dave Hutchison, Environment Canada, Hull, Quebec

13:30-14:00 **Bioremediation Field Initiative - Performance Evaluation at Actual Sites** - John Matthews (USEPA), Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma

14:00-14:30 **Review of Six Technologies for *In-Situ* Bioremediation of Dissolved BTEX in Groundwater** - Lloyd Lemon, University of Waterloo, Waterloo, Ontario

14:30-15:00 Coffee Break

15:00-15:30 ***In-Situ*, On-Site Microbiological Clean-up of Soils Contaminated with Toxic Wood Preservatives** - Alan Seech and Igor Marvan, Dearborn Chemical Company Limited, Mississauga, Ontario

15:30-16:00 ***In-Situ* Bioremediation of Soils in a Northern Environment Contaminated with Fuel Oil** - O.P. Quinn, A.D. Walker and R.J. Lorimer, Klohn Leonoff Yukon Limited, Whitehorse, Yukon

16:00-16:30 **Surface Bioreactor to Clean Soil/Waste Contaminated with Hydrocarbons and Salt** - Lin Callow (CPA), Gulf Canada Resources Inc., Calgary, Alberta

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Symposium Sponsors

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  - Alberta Environmental Research Trust
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  - B.C. Environment, Lands and Parks
  - Canadian Petroleum Association
  - Canadian Petroleum Products Institute
  - Energy, Mines and Resources Canada
  - Environment Canada
  - New Brunswick Department of the Environment
  - Newfoundland Department of Environment and Lands
  - Ontario Ministry of the Environment
  - Prince Edward Island Department of the Environment
  - U.S. Environmental Protection Agency
- **Environment Canada - DESRT**
- **British Columbia Water and Waste Association**

March 26, 1992 Day 2

SESSION 3 EXCAVATION AND TREATMENT

Session Chairperson - John Matthews (USEPA), Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma

08:30-09:30	**Demonstration and Evaluation of Treatment Technologies for the Remediation of Contaminated Soils from the Pacific Place Site in Vancouver, B.C.** - Sandra Whiting, SCS Engineers, Bellevue, Washington
09:30-10:15	**Remediation Activities at the Canada Creosote Site in Calgary, Alberta** - Walter Ceroici, Alberta Environment, Edmonton, Alberta, and Colin Beresford, Acres International, Calgary, Alberta
10:15-10:45	Coffee Break
10:45-11:15	**Leachate Characteristics of Gasoline Contaminated Soil** - Dr. Bruce Bauman, American Petroleum Institute, Washington, DC
11:15-11:45	**Evaluation of Soil Washing and Bio-Slurry Reactor Treatment for Soil Contaminated with PCBs and Heavy Metals** - Maria Dober, Environment Canada, and Louise Steward, New Brunswick Department of the Environment
11:45-12:15	**Land Treatment of Alberta Oilfield Wastes and Reclamation of Treatment Sites** - Dr. R. M. Danielson, Kananaskis Centre for Environmental Research, The University of Calgary, Calgary, Alberta
12:15-13:15	Lunch Break

Symposium Objectives

Papers presented during this technology transfer symposium aim to inform delegates about research on innovative approaches to clean up contaminated groundwater and soil. Accompanying technical posters will encourage technology vendors and delegates to discuss the emerging and existing remediation technologies displayed during the symposium.

Who Should Attend

Researchers, consultants, regulators, and professionals from the petroleum, wood preserving and organic chemicals industries should attend.

March 26, 1992 Day 2

SESSION 4 PUMPING AND TREATMENT / SOIL VENTING

Session Chairperson - Bob Sheppard, Pollution Abatement Branch, Environment Canada, North Vancouver, B.C.

13:15-13:45 **Overview of the USEPA's Subsurface Cleanup and Mobilization Processes (SCAMP) Initiative** - Dr. Steve Schmelling (USEPA), Robert S. Kerr Environmental Research Laboratories, Ada, Oklahoma

13:45-14:15 **Iron and Manganese Pre-treatment for Pump and Treat Clean-up Systems** - Marc Halevy, Wastewater Technology Centre, Burlington, Ontario

14:15-14:45 **Options for Cleaning up Subsurface Contamination at Alberta Sour Gas Plants** - Tad L. Dabrowski, Piteau Engineering Ltd., Calgary, Alberta

14:45-15:15 Coffee Break

SESSION 5 INDUSTRY AND GOVERNMENT INITIATIVES

Session Chairperson - George Collin, Amoco Canada Petroleum Company Ltd., Calgary, Alberta

15:15-15:45 **Regional Hydrocarbon-Contaminated Soil Recycling Facility Standards** - Randall Warren (CPPI), Shell Canada Ltd., Calgary, Alberta

15:45-16:15 **USEPA's Technology Support Program for Cooperation Between Researchers and Operators** - John Matthews (USEPA), Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma

16:15-16:30 **Closing Remarks** - George Hill, Environment Canada, Technology Development Branch, Hull, Quebec

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IN-SITU BIOREMEDIATION SYMPOSIUM '92

NIAGARA-ON-THE-LAKE
ONTARIO, CANADA
SEPTEMBER 20-24, 1992

Program:

- Fundamental processes controlling *in-situ* bioremediation.
- Ideal contaminants for *in-situ* biological treatment
- Hydrogeological environments best suited to bioremediation.
- Lessons learned from demonstration projects.
- Ways to assess the success or failure of the process.

For Further Information:

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Canadian Association on Water Pollution Research and Control
Wastewater Technology Centre
867 Lakeshore Road
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Ontario. L7R 4L7
Phone: (416) 336-4588 Fax: (416) 336-4765

Programme final

PRESSC\DESRT

Deuxième symposium annuel sur

la restauration des eaux souterraines et des sols contaminés

parrainé par :

Membres du PRESSC

Environnement Canada - DESRT

Association des eaux et des déchets de la Colombie-Britannique

25 et 26 mars 1992

Hôtel Vancouver
Vancouver (Colombie-Britannique)

PROGRAMME DU SYMPOSIUM

25 mars 1992 1er jour

7 h 30 - 8 h 30	Inscription

SÉANCE N° 1

PROGRAMMES DE RECHERCHES SUR LES EAUX SOUTERRAINES ET LES SOLS CONTAMINÉS

Président - Alex Lye, Environnement Canada, Burlington (Ontario)

8 h 30 - 8 h 45	**Discours d'ouverture** - Alex Lye, Environnement Canada, Centre environnemental de Burlington, Burlington (Ontario)
8 h 45 - 9 h 05	**Conférencier d'honneur** - Barry Olsen, Ministère de l'environnement de la Colombie-Britannique(Terres et parcs), Vancouver (C.-B.)
9 h 05 - 9 h 25	**Mise à jour concernant le Programme national de restauration des eaux souterraines et des sols contaminés (PRESSC)** - Alex Lye, Environnement Canada, Centre environnemental de Burlington, Burlington (Ontario)
9 h 25 - 9 h 40	**Aperçu du programme de création et de démonstration des techniques de restauration (DESRT)** - George Hill, Environnement Canada, Direction du développement technologique, Hull (Québec)
9 h 40 - 10 h 00	**Activités de recherche du Groupe de travail sur les eaux souterraines et les sols de l'Institut canadien des produits pétroliers (CPPI)** - Adolfo Silva (CPPI), *Petro-Canada Inc.*, Calgary (Alberta)
10 h 00 - 10 h 30	Pause
10 h 30 - 11 h 00	**Conseil consultatif de recherche en environnement de l'Association pétrolière du Canada (CPA) - Aperçu des activités de recherche** - George Collin (CPA), *Amoco Canada Petroleum Company Ltd.*, Calgary (Alberta)
11 h 00 - 11 h 30	**Aperçu des recherches sur les sols et les eaux souterraines menées par l'Institut américain du pétrole (API)** - Bruce Bauman, Institut américain du pétrole, Washington (D.C.)
11 h 30 - 12 h 00	**Besoins et priorités du programme DESRT en matière de recherche-développment et de démonstration** - Brian Whiffin, *CH2M Hill Engineering Ltd.*, Waterloo (Ontario)
12 h 00 - 13 h 30	Déjeuner

Programme du symposium

Le programme sera axé sur les activités de recherche menées par le PRESSC et certains de ses membres. Les communications donneront aux participants un aperçu de divers programmes de recherches portant sur des techniques innovatrices et leur fourniront le résultat des projets de recherche réalisés en vertu du PRESSC, du DESRT et d'autres programmes. En outre, une quinzaine de vendeurs sélectionnés présenteront leurs techniques d'assainissement au cours de séances d'affichage.

25 mars 1992 1er jour

SÉANCE N° 2

BIORESTAURATION

Président - Dave Hutchison, Environnement Canada, Direction du développement technologique, Hull (Québec)

13 h 30 - 14 h 00	**Initiative de biorestauration sur place - Évaluation de la performance sur les lieux** - John Matthews (USEPA), *Robert S. Kerr Environmental Research Laboratory*, Ada (Oklahoma)
14 h 00 - 14 h 30	**Étude de six techniques pour la biorestauration sur place du BTEX dissous dans les eaux souterraines** - Lloyd Lemon, Université de Waterloo, Waterloo (Ontario)
14 h 30 - 15 h 00	Pause
15 h 00 - 15 h 30	**Assainissement *in situ*/sur place des sols contaminés par les produits toxiques de préservation du bois** - Alan Seech et Igor Marvan, *Dearborn Chemical Company Limited*, Mississauga (Ontario)
15 h 30 - 16 h 00	**Biorestauration *in situ* des sols contaminés par le mazout dans le nord** - O.P. Quinn, A.D. Walker and R.J. Lorimer, *Klohn Leonoff Yukon Limited*, Whitehorse (Yukon)
16 h 00 - 16 h 30	**Utilisation d'un bioréacteur de surface pour assainir les sols et les résidus contaminés par des hydrocarbures et des sels** - Lin Callow (CPA), *Gulf Canada Resources Inc.*, Calgary, (Alberta)

Promoteurs du symposium

Les organismes suivants parrainent le symposium :

- **Membres du PRESSC**
  Ministère de l'Environnement de l'Alberta
  Fonds de recherches environnementales de l'Alberta
  Institut américain du pétrole
  Ministère de l'environnement de la Colombie-Britannique (Terres et parcs)
  Association pétrolière du Canada
  Institut canadien des produits pétroliers
  Énergie, Mines et Ressources Canada
  Environnement Canada
  Ministère de l'Environnement du Nouveau-Brunswick
  Ministère de l'Environnement de l'Ontario
  Ministère de l'Environnement de l'Île-du-Prince-Édouard
  Ministère de l'Environnement et des terres de Terre-Neuve
  Agence de protection de l'environnement des États-Unis
- **Environnement Canada - DESRT**
- **Association des eaux et des déchets de la Colombie-Britannique**

26 mars 1992 2e jour

SÉANCE N° 3 EXCAVATION ET TRAITEMENT

Président - John Matthews (USEPA), *Robert S. Kerr Environmental Research Laboratory*, Ada (Oklahoma)

8 h 30 - 9 h 30	**Démonstration et évaluation des techniques de traitement pour la restauration des sols contaminés du chantier de Pacific Place à Vancouver (C.-B.)** - Sandra Whiting, *SCS Engineers*, Bellevue (Washington)
9 h 30 - 10 h 15	**Activités de restauration à l'usine de *Canada Creosote* située à Calgary (Alberta)** - Walter Ceroici, ministère de l'Environnement de l'Alberta, Edmonton (Alberta), et Colin Beresford, entreprise *Acres International*, Calgary (Alberta)
10 h 15 - 10 h 45	Pause
10 h 45 - 11 h 15	**Caractéristiques des lixiviats d'un sol contaminé par l'essence** - Bruce Bauman, Institut américain du pétrole, Washington (D.C.)
11 h 15 - 11 h 45	**Évaluation des techniques de lavage des sols et de traitement biologique des boues en réacteur pour les sols contaminés par les PCB et les métaux lourds** - Maria Dober, Environnement Canada, et Louise Steward, ministère de l'Environnement du Nouveau-Brunswick
11 h 45 - 12 h 15	**Traitement des déchets des champs de pétrole de l'Alberta par le sol et régénération des chantiers de traitement** - Dr. R.M. Danielson, Centre Kananaskis de recherche sur l'environnment, Université de Calgary, Calgary (Alberta)
12 h 15 - 13 h 15	Déjeuner

Objectifs

Les communications présentées au cours du symposium qui porte sur le transfert de technologie visent à informer les participants au sujet des recherches menées sur les méthodes innovatrices d'assainissement des eaux souterraines et des sols contaminés. En outre, des séances d'affichage permettront aux vendeurs de techniques et aux participants de discuter des techniques de restauration actuelles et nouvelles décrites au cours du symposium.

Participants

Le symposium intéressera les chercheurs, les experts-conseils, les responsables de la réglementation ainsi que les personnes qui travaillent dans les secteurs industriels du pétrole, de la préservation du bois et des produits chimiques organiques.

26 mars 1992 2^e jour

SÉANCE N° 4

POMPAGE ET TRAITEMENT / VENTILATION DES SOLS

Président - Bob Sheppard, Pollution Abatement Branch, Environment Canada, North Vancouver (C.-B.)

13 h 15 - 13 h 45	**Aperçu du Programme d'assainissement et des procédés de mobilization de la zone souterraine de l'Agence de protection de l'environnement des États-Unis (USEPA)** - Steve Schmelling (USEPA), Robert S. Kerr Environmental Research Laboratory, Ada (Oklahoma)
13 h 45 - 14 h 15	**Prétraitement au fer et au manganèse pour les systèmes de pompage et de traitement** - Marc Halevy, Centre technique des eaux usées, Burlington (Ontario)
14 h 15 - 14 h 45	**Méthodes d'assainissement de la subsurface contaminée dans les usines de gaz sulfureux de l'Alberta** - Tad L. Drabowski, *Piteau Engineering Ltd.*, Calgary (Alberta)
14 h 45 - 15 h 15	Pause

SÉANCE N° 5

INITIATIVES INDUSTRIELLES ET GOUVERNEMENTALES

Président - Session Chairperson - George Collin, *Amoco Canada Petroleum Company Ltd.*, Calgary (Alberta)

15 h 15 - 15 h 45	**Normes des installations régionales de recyclage des sols contaminés par les hydrocarbures** - Randall Warren (CPPI), *Shell Canada Ltd.*, Calgary (Alberta)
15 h 45 - 16 h 15	**Programme de soutien à la technologie de l'EPA pour la coopération entre les chercheurs et les opérateurs** - John Matthews (USEPA), *Robert S. Kerr Environmental Research Laboratory*, Ada (Oklahoma)
16 h 15 - 16 h 30	**Discours de clôture** - George Hill, Environnement Canada, Direction du développement technologique, Hull (Québec)

SYMPOSIUM SUR LA BIORESTAURATION *IN-SITU* '92
NIAGARA-ON-THE-LAKE, ONTARIO, CANADA
20-24 SEPTEMBRE 1992

Programme:

- Les processus fondamentaux qui régissent la biorestauration *in-situ*.
- Les contaminants qui se prêtent le mieux au traitement biologique *in-situ*.
- Les milieux hydrogéologiques qui se prêtent le mieux à la biorestauration.
- Les études sur le terrain.
- L'évaluation du succès (ou de l'échec) du procédé.

Pour de plus amples renseignements:

Veuillez communiquer avec:

Bev Pasian
L'association canadienne pour la recherche sur la pollution de l'eau et sa maîtrice
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"Review of Six Technologies for *In-Situ* Bioremediation of Dissolved BTEX in Groundwater"
Lemon..8.0

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PUMPING AND TREATMENT/SOIL VENTING

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INDUSTRY AND GOVERNMENT INITIATIVES

SECTION 5

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"US EPA's Technology Support Program for Cooperation Between Researchers and Remediation Decision-Makers"
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DELEGATE LIST

SECTION 6

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The organizing committee would like to record its appreciation of the efforts of the speakers and the moderators.

Le Comité d'organisation du Symposium aimerait remercier les conférenciers et les animateurs de leur précieuse collaboration.

GASReP/DESRT

2ND ANNUAL SYMPOSIUM ON GROUNDWATER AND SOIL REMEDIATION

March 25-26, 1992

KEYNOTE ADDRESS

"PACIFIC PLACE REMEDIATION REALITIES"

BARRY OLSEN, PROJECT MANAGER
PACIFIC PLACE REMEDIATION PROJECT
BC ENVIRONMENT
MINISTRY OF ENVIRONMENT, LANDS & PARKS

PACIFIC PLACE REMEDIATION

Thank you. It is a privilege and a great pleasure for me to be with you today. As Alex Lye knows, I leaped at the opportunity to share the lessons learned from Expo site remediation with you. Nobody else should have to go through what we did.

The Expo site is without doubt one of Canada's most well known pieces of real estate. It is also one of the least understood.

This apparent contradiction lies at the heart of the difficulties experienced during the early stages of the remediation project.

It has also presented us with what may well prove to be our greatest challenge.

I can perhaps best demonstrate what I mean by telling you of an incident that occurred shortly after residential grade soil finally began moving off the site.

> Someone had observed trucks dumping soil on land being prepared as a golf course. Suspecting that the material came from the Expo site, they followed the truck back to where it was loading.
>
> Soon after, we got a call accusing us of sneaking toxic soil into their community. The truck had been followed to the Expo site, we were told.
>
> We knew that was impossible, as no soil had been trucked out that week.
>
> The caller was adamant. The truck had returned to the Expo Site and been reloaded. We checked some more and told the caller the trucks he was talking about were working on an adjoining property (a former service station site, in fact) and had nothing to do with us.
>
> "Oh," said the caller. "That's all right then."

This attitude illustrates the negative stigma attached to the Expo lands and the public misunderstanding of contamination. The province's sale of the site to a private developer was still controversial. The news media reports at the time of the sale and thereafter headlined the existence of toxic wastes on the Expo site and had created in the public mind an image of the site as being contaminated from end to end.

We knew from our investigations that the real picture was quite different. In actuality, less than two percent of the volume of soil on site contains potentially hazardous soils. But once public perception had been shaped, changing it proved exceedingly difficult.

Let me go back in time for a moment. At the outset of the project we recognized that a good communications and public consultation strategy would be essential to the project's success. Our overall objective was to provide all information in a timely and low-key manner to the media and to the public. Newsletters, fact sheets, media releases, information bulletins, open houses, interviews - all were to be used.

The natural political desire to avoid bad publicity, however, resulted in delays in implementing our strategy. Due to erroneous reports that Expo soils were "toxic", our pro-active communications approach was quickly supplanted by crisis communications. In retrospect, we should have quietly spent more time at the outset obtaining support for our communications strategy at the various political levels.

Efforts should be made to use language that reflects the public's perception of reality rather than that of scientists and technical experts. One of the lessons learned is that the public generally interprets "contaminated" to be an all or nothing state. To most people, saying soil is "slightly contaminated" is like saying a person is "slightly dead". So we are now trying to use more relative or accurate terms to communicate our message, such as "degraded soils", or "industrial residues". The question of terminology is important. It can either lead to better understanding and greater credibility or accusations that government is trying to mislead the public.

There are proven technologies such as that pictured for PCB treatment. But we all know that remediation is a rapidly evolving business. Rarely does a week pass, in fact, that I do not get a call from someone claiming to have the ultimate solution to the Expo soils and groundwater problem. Innovative technology is, of course, a focus of this symposium.

But remediation is also evolving in other areas. What happens at the Expo site is setting the trend for remediation in the rest of British Columbia. We understand that other provinces are also watching our progress with considerable interest.

Allow me to share with you some of the other remediation realities as we have experienced them at the Expo site - often through the school of hard knocks. These include regulatory, legal, political and management realities.

Regulatory Realities:

First up are the regulatory realities.

When the Expo lands were sold to Concord Pacific in 1988, the province agreed to clean up the site to meet provincial standards. At the time, there were none. So the Ministry of Environment and its expert advisors developed them. The guiding principle was protection of public health and the environment.

The BC standards were completed in 1990. This set the stage for the remediation of the Pacific Place lands (as the Expo lands were renamed). Two approaches are included in the provincial standards - the numerical concentration approach and the one that uses risk assessment and risk management. Both are being applied at Pacific Place.1

For comparison to the risks shown on the illustration, the BC target is one in one million over a lifetime.

These standards became the basis for the BC criteria and later the national criteria endorsed in 1991 by the Canadian Council of Ministers of Environment. Well done you say. At last there were some benchmarks for remediation!

But that was just the beginning. I have heard medical doctors argue vociferously that the standards are far too cautious and conservative, and hence too costly to implement. I have also been at a public meeting where soil standards were explained and where an angry resident stood up and yelled "We don't care how clean the Expo soil is, we don't want it here".

Municipalities, Fisheries and Oceans Canada and other federal and provincial agencies are interpreting the standards very strictly, making it extremely difficult to dispose of normal commercial-industrial fill. Even a slight exceedance of a substance is enough to reject an entire stockpile of soil. For some substances, for example arsenic, what one province or country considers acceptable for landfill disposal is considered special waste in BC.

Public understanding of the standards, and by extension, of the use of statistics is virtually non-existent. You may understand the meaning of "risk assessment" and "upper confidence level of the mean", but I assure you your public does not. The use of risk assessment and in-place management has the potential to reduce remediation costs by more than half. But people will not accept what they do not understand. I implore you to explain your work in layman's terms.

Legal Realities:

Legal realities are an important and evolving component of remediation.

The use of the numerical concentration and in-place management approaches have their own legal peculiarities.

First the concentration approach. Who has legal responsibility for the contamination at residential or commercial-industrial disposal sites, if any is found in the future? Once soil has been tested to confirm that it meets the landfill requirements, and the landfill owners have agreed to accept it on that basis, then liability shifts to them. This suggests that landfill operators will want iron-clad assurances of soil quality.

The question often arises as to what the downstream liability for contamination is when in-place management is used. For example, if this approach is used at Pacific Place and contaminants remain on site, the province is responsible for claims against Concord Pacific which are due to contaminants.

Another debate arises if contamination left in place affects the marketability of property. Who should bear the cost? The answer is not clear and is a hot topic of discussion with Concord Pacific.

Notations on title where contaminants are managed in place are another significant concern relating to marketability. Are they really required for condos on the 25th floor? Perhaps a better idea would be to have a register of remediated and contaminated properties which could be checked when properties are sold, and especially if redevelopment is considered.

A significant concern arises when long-term monitoring of a site is considered. When a property is sold by Concord Pacific and the site has been remediated to meet provincial standards, should the province or the new owners have on-going responsibility for the monitoring?

These difficult legal questions must be answered in implementing the standards, and especially if in-place management is to be used effectively.

The bottom line is that there is still a great deal of work to be done to get general understanding and acceptance of the standards and their implementation. As researchers and technical experts, you may comfort yourself that the standards being applied today err on the side of safety. Convincing others of that is a challenge for all of us.

Municipal Realities:

There are also remediation realities concerning municipalities.

Municipalities have an important role to play in remedial efforts in cities. In general, the City of Vancouver has taken the approach that total responsibility for contaminants at Pacific Place is the province's. They have ensured that legal arrangements are in place to keep it that way permanently.

The city has a Utilities Design Agreement with the province and Concord Pacific to ensure that its utilities are fully protected. The agreement also ensures the city will not be liable for any legal actions relating to contaminants or major remedial works such as barrier walls and liner caps.

Special and very costly measures like $1000 gaskets and pipe wrapping to prevent groundwater infiltration to the sewers and water mains are also called for. Similar measures are proposed for other parcels. One could also anticipate the city demanding such measures for private parcels of land containing contaminants.

It was recognized at the outset that Parcel 9, shown here, was the most contaminated area of Pacific Place. To avoid enormous costs of remediation, it was decided to use in-place management and make the parcel into a park.

The City, however, did not want the long term responsibility or liability for the contamination under Andy Livingstone Park. The province therefore agreed to indemnify the city and to accept the land from Concord Pacific and in turn lease it back for 999 years to the city.

This raises an interesting question. Such an arrangement is viable between the province and the city, but what happens when a private developer wishes to use in-place management in similar circumstances to reduce costs. Would similar such arrangements be possible or practical?

At Pacific Place, for each lot where remediation is completed, the province is issuing to the city a "Confirmation of Compliance" which indicates the property has met the provincial standards for the use intended, in most cases residential. A copy also goes to Concord Pacific. This certificate is an important piece of paper - for the developer, and for its bankers in particular. So far, five have been issued.

Political Realities:

What about the realities of politics and governments in remediation, apart from the regulatory role?

A September article in Inside Guide by James Gillies focussed on why governments are so unpopular. The author's position is that governments have forgotten their basic purpose, which is to help people solve their problems.

Let's accept for a moment that this is true. And with this in mind, let's briefly review the soils management situation which has arisen from Lower Mainland municipalities passing bylaws stopping all but residential level soils from being deposited in their communities. The reason the councils took such action was to respond to public concerns raised by erroneous reports about the "toxic" nature of the soils, not to the actual facts of the matter. Perception became reality. Emotion, not reason, ruled the day.

In fact, the location to which the soils were initially to go was a former garbage dump two kilometres from the Fraser River surrounded by a $6 million leachate control system. Further, the receiving site had undergone two federal environmental impact reviews which concluded there would be no significant impact on the environment.

So what are the implications of the bylaws?

1. To date at Pacific Place, extra stockpiling, segregation of soils, testing, double handling of soils, and additional monitoring has increased costs to tax payers in the order of $500,000 - $700,000. The increase in protection of health and environment? Negligible. If such practice continues, it will cost significantly more to redevelop land within the Lower Mainland.

2. The by-laws reinforce the Not-In-My-Back-Yard or NIMBY syndrome. In addition to the five communities with bylaws, there are other Lower Mainland centres ready to pass their own. No municipality wants to be the dumping ground for others. This makes it virtually impossible at a reasonable cost to deposit commercial-industrial soils anywhere.

3. The by-laws fail to recognize the interdependence of Lower Mainland communities. It is becoming increasingly expensive to do any excavations on commercial-industrial sites. Moreover, it further complicates the construction process and necessitates additional municipal staff for monitoring. Redevelopment could be seriously impaired. (Example: Municipalities with restrictive bylaws must now deposit their commercial-industrial soils outside their municipality. At some stage, this could halt progress. It is already impeding it).

4. The fear of people that the soils were unsafe was confirmed in the public's mind by the municipal governments taking action contrary to that of the province. The by-laws reinforce a mistrust of government when cooperation and working together for mutual solutions are required.

5. BC Environment has developed standards for dealing with contaminated soils that apply to the entire province and are consistent with the national criteria. For municipalities to impose more stringent standards undermines the implementation of national and provincial standards. In effect, already conservative standards are effectively being made more stringent for no real benefits.

Whenever possible, municipalities need to be reminded of these implications by those most affected - including you, the participants at this symposium. And governments must be prepared to take difficult decisions, based on specific objectives and a long-term strategy in mind.

Cooperation between other provinces, and Canada and the United States, should also be part of the solution. There may be advantages of scale and tremendous cost savings if an interdependent network of treatment sites and technologies is created. It makes little sense to have an over-capacity in one province, and none in another when reciprocal arrangements are possible.

Management realities:

There are also a number of management realities related to the remediation of Pacific Place. Due to lack of time I'll simply note the anomalies.

1. Research and site investigations:

Just after the first phase of the site investigations, we estimated the amount of special waste laden soil to be about 110,000m^3. Now that we have completed our site studies and the remedial plans, the figure has dropped dramatically, to about 40,000m^3. With the application of in-place management, only 20,000m^3 will now likely have to be dealt with. This changes significantly the costs of remediation, and increases the options for dealing with such soils. The figures also illustrate just how important good research is in defining areas of special waste and determining management strategies.

2. Sampling and analytical procedures.

The ministry assured municipalities it was satisfied with the procedures for sampling and testing the Expo soil. But municipalities did not trust the province. They insisted that the province's sampling and testing procedures be acceptable to them. The ministry spent considerable effort and over two months working with municipal officials and their consultants to review this issue. In the end, the ministry's procedures were confirmed.

Another problem arose when two labs used different analytical processes to test a substance, in this instance chromium. The results were different by an order of magnitude, and led to considerable retesting by one lab and a significant reduction in volume of contaminated soils. Industry and the province must establish commonly accepted sampling and analytical procedures to avoid similar problems arising.

3. Requirements of the disposal sites

In the future, to allay public concerns about the disposal of commercial-industrial soils in communities, an environmental evaluation of the receiving site will likely be required by municipalities. The ministry is currently reviewing this issue to see what involvement, if any, it should have in this process.

Landfill operators are also likely to be more diligent about obtaining proof from contractors that soil meets the soil quality standards. This will provide a form of liability protection.

4. Specialized construction procedures

In dealing with potentially contaminated soils, there are a variety of special construction management procedures that must be followed.

- Occupational health and safety measures are required, such as training and orientation in material handling, safety and emergency procedures, the wearing of specialized equipment, and decontamination.

- Soils management procedures have been developed. These include soil segregation and testing; treatment of tainted groundwater; and monitoring including such cumbersome measures as truck chits in triplicate for each load.

Obviously, extra time and costs are attributable to these procedures.

5. Need for storage and treatment of above-commercial-industrial and special waste soils.

Since at present, even commercial-industrial level soils cannot be moved from Pacific Place, it follows that special waste soils are even more difficult to dispose of.

The ministry is currently reviewing its options for the development of a storage and treatment facility siting process to handle seriously contaminated soils.

In addition, as part of the National Contaminated Sites Remediation Program, six companies are conducting Pacific Place special waste treatment studies focussing on four technologies. These are designed to demonstrate the effectiveness of treatment on special waste soils from the site in an environmentally responsible and cost-effective manner. The ministry will provide its unbiased evaluation of the technologies to other municipalities to assist in the treatment of soils at other sites. Sandra Whiting and Bob Ferguson will be discussing this topic in detail with you tomorrow.

Some of the problems associated with remediation could be solved through greater cooperation among government, industry and business in research and development. I urge you to discuss the establishment of a remediation data bank, perhaps within universities or environmental ministries, for the collection and dissemination of information.

Soils Management Task Force:

As you have gathered by now, there are a number of problems for which we do not yet have solutions. To assist the ministry, a soils management task force was established in August of last year. The task force was set up as an advisory body to the ministry and BC municipalities on soils management issues and concerns. The task force report and recommendations will be released in late March, 1992. It will recommend development of guidelines for preparation of soil deposit bylaws which are consistent with the provincial criteria for managing soil quality.

There is great hope that the report will be the catalyst for resolving issues of soil disposal in the province. I urge you to obtain copies when it becomes available.

In conclusion, I want to emphasize that the focus at Pacific Place is now not so much on its past, as on what we can learn from the present, and what will come in the future.

Pacific Place will be more than a vital and attractive addition to downtown Vancouver. It will continue to help refine procedures, standards and policies which can be used in dealing with other historical industrial sites undergoing redevelopment in British Columbia and elsewhere.

If when you leave this hall today you should happen to drive by Pacific Place and see a truck laden with soil emerging from the site, you now know what considerable effort is behind its removal.

Oh, one final thing -- take a good look at the driver!

Thank you!

1.0

Update on the National Groundwater and Soil Remediation Program (GASReP)

By

Alex Lye

GASReP Coordinator

Environment Canada

The national Groundwater and Soil Remediation Program (GASReP), supported jointly by government and the petroleum industry, targets research on innovative ways to clean up groundwater and soil contaminated with petroleum hydrocarbons, and conducts technology transfer sessions.

Within its broad context as an initiative for research, development and demonstration (R, D & D) of innovative clean-up technologies, GASReP now targets basic *applied* research and/or technology development only. Industry partners and players in other government programs will be encouraged to extend GASReP's research findings to the final stage of technology demonstration.

During 1991/92, GASReP shifted its attention from starting new projects to evaluating the program, setting a new direction, and establishing a better way to seek ideas for projects. Unlike previous years, only three projects began last year.

Of these three new projects, two are classified under technology development and one under technology assessment. Projects in the first category comprised *Iron and Manganese Pre-treatment for Pump and Treat Clean-up Systems* and *Surface Bioreactor to Clean Soil/Waste Contaminated With Petroleum Hydrocarbons*. The project in the second category dealt with a *Review of Six Technologies for In-Situ Bioremediation of BTEX in Groundwater*. Researchers for these projects will present their findings during the GASReP/DESRT Symposium.

Before settling on the program's current direction, interests and research needs, GASReP members considered the program's achievements, concerns of government and industry, and the research needs identified in earlier consultants reports. In Appendix A, the document entitled "*Current Program Direction, Interests, and Research Needs, August, 1991*" elaborates on these topics.

Under its *current direction*, GASReP will continue to concentrate on innovative technologies for cleaning groundwater and soil contaminated with petroleum hydrocarbons, but will focus on contamination in less porous media (e.g silt, clay, bedrock) rather than in sand and gravel. Seed money will be provided to encourage other agencies to co-fund projects with GASReP.

The *current interests and research needs* identify knowledge gaps in areas such as enhanced soil vapour extraction, biological and thermal treatment of excavated soil, soil washing, *in-situ* and on-site bioremediation with native microorganisms, and others.

To get ideas for projects that address its interests and research needs, GASReP has opted to solicit proposals via a two-step process rather than accept unsolicited proposals. In the first step, proponents will submit Letters of Interest (short proposals) that target the program's current research needs. After GASReP's Technical Committee has evaluated and ranked the Letters of Interest, selected proponents will be invited to take the second step of submitting detailed proposals. The same committee then chooses the following year's projects from among these proposals.

This streamlined project selection procedure went into effect for the first time during 1991/92. After issuing a call for Letters of Interest in August, 1991 GASReP received eighty-four responses. Of these, fifteen were short-listed by GASReP's Technical Committee in October, 1991. Eleven proponents eventually submitted detailed proposals in January, 1992. During its meeting in March, 1992 the Technical Committee will select projects for 1992/93 from the eleven candidate proposals listed in Appendix B.

Plans for 1992/93 include funding projects, maintaining partnerships and setting up others, and continuing technology transfer. GASReP will co-fund its new projects and continue to work with its partners on the bioreactor. Preserving existing links with its member agencies will ensure that duplication of research is avoided. To better achieve this objective, GASReP plans to reach out to players on other national and international programs on remediation technologies. Involvement with these groups will include taking part in their technology transfer sessions, and inviting them to the next GASReP/DESRT Symposium.

GASReP continually strives to find ways to resolve some of the petroleum industry's environmental problems. To this end, the program co-funds projects on applied research and technology development, establishes and maintains links with the petroleum industry and other programs on remediation technologies, and convenes or takes part in technology transfer sessions.

APPENDIX A

Current Program Direction, Interests and Research Needs

1.3

NATIONAL GROUNDWATER AND SOIL REMEDIATION PROGRAM

(GASReP)

Current Program Direction, Interests,
and Research Needs

August, 1991

This document reflects the outcome of recent meetings of GASReP's four technical committees.

All four committees decided on the current direction for GASReP, but each one specified its interests and research needs.

Each committee focuses on remediation technologies in one of the following categories:

- **excavation and treatment;**
- ***in-situ* bioremediation;**
- **pumping and treatment; and**
- ***in-situ* volatilization and off-gas treatment.**

CURRENT DIRECTION OF GASReP

- Petroleum hydrocarbon contamination linked to activities in the petroleum industry
- Research into ways to remove these contaminants from groundwater and/or soil (primarily silt and clay)
- Innovative remediation technologies or creative applications of conventional technologies
- Technologies that can be used by anyone after they have been developed, but vendor-specific ones as well
- Projects on *applied* research, development or demonstration of proposed innovations
- Seed money to encourage other agencies to co-fund research projects

CURRENT INTERESTS AND RESEARCH NEEDS

A. EXCAVATION AND TREATMENT

1. Technologies

- Extraction of Contaminants
    - Surfactants
    - Soil Washing
- Biological Treatment
    - Enhanced Land Treatment
    - Bioreactor (dry and slurry phases)
- Thermal

    (for fine-grained materials only; approach must be new)

2. Contaminant Component

- Excavated soils

CURRENT INTERESTS AND RESEARCH NEEDS (Continued)

B. *IN-SITU* BIOREMEDIATION

1. Technologies

- *In-situ*
- Native microbial populations only; enhanced *in-situ*, or *ex-situ* and then reinjected

2. Contaminant Component

- All (e.g residual, capillary zone, plume) except free product and vapour phase

3. Technology Evaluation

- Monitoring and evaluation essential

CURRENT INTERESTS AND RESEARCH NEEDS (Continued)

C. PUMPING AND TREATMENT

1. Technologies

- Extraction of Contaminants (Accelerated Pumping)
  - to enhance removal of contaminants from the capillary fringe using solvents and surfactants
  - to remove contaminated groundwater
  - to optimize free product recovery
  - to optimize long-term pumping operations
- Treatment for Groundwater and Vapours
  - advanced oxidation processes (AOP) to destroy organics
  - stripping of contaminants from groundwater
  - groundwater pretreatment to remove water quality parameters, e.g. Fe, Mn, hardness, that could interfere with treatment processes for organic contaminants
  - treatment for oxygenates (e.g. MTBE and others)

2. Contaminant Component

- All (e.g. vadose zone, capillary zone, free product, dissolved in groundwater) except the vapour phase

3. Site Characterization

- Site conditions where pumping technologies could be successful

CURRENT INTERESTS AND RESEARCH NEEDS (Continued)

D. *IN-SITU* VOLATILIZATION AND OFF-GAS TREATMENT

Technologies must have potential application and benefit within a relatively short time, and be cost-effective.

Proposed work must supplement developing technologies, or enhance existing ones.

1. Technologies

- Extraction of Contaminants
    - Soil Vacuum Extraction (SVE) - High Priority

      Effect of moisture in zones of residual product; role of sorption/desorption on SVE treatment times
    - *In-Situ* Aeration - High Priority

      Operating parameters for air injection wells below the water table

      Effect of *in-situ* aeration; does it enhance biodegradation or volatilization?
    - Steam Stripping - Medium Priority
- Off-Gas Treatment
    - Biological treatment
    - Advanced oxidation processes (AOP)
    - Catalytic regeneration of carbon

2. Contaminant Component

- Vadose and capillary zones

3. Technology Evaluation

- Monitoring and evaluation of SVE in tight soils

APPENDIX B

Candidate Proposals for Project Selection, 1992/93

Candidate Proposals

Proposal Number	Proposal Title
11	Genetic Improvement of Bioemulsifier Production by *Pseudomonas aeruginosa* UG2 for Subsequent Use in Solubilization and Biodegradation of Hydrocarbons in Soil
27	Soil Remediation Using Supercritical Fluid Extraction
30	Bench-Scale Study of the Photo-Oxidation of BTEX Mixtures in Air Using Ultraviolet Irradiation and Hydrogen Peroxide
35	Comparison of Bioreactor Technologies for the Effective Remediation of Hydrocarbon Treated Soils in Canada
41	Aerobic Microbial Metabolism of Thiophenic Compounds Found in Petroleum
47	Efficient Addition Technology for In Situ Bioremediation
53	Composting Treatments for Contaminated Soil
62	Complementary Field Characterization Techniques for the Investigation of LNAPLs in Fractured Bedrock
64	Laboratory and Field Demonstration of Existing and Emerging Technologies for Feasibility Evaluation, Monitoring and Validation of Bioremediation
78	A Solid Oxidant Process for Off-Gas Treatment
84	Enhanced Biofiltration of Waste Off-Gas Streams

2.0

OVERVIEW OF THE DEVELOPMENT AND DEMONSTRATION OF SITE REMEDIATION TECHNOLOGY (DESRT) PROGRAM

BY

GEORGE H. HILL

CHIEF, INDUSTRIAL INCENTIVES DIVISION

ENVIRONMENT CANADA

ABSTRACT

With funding of $50 million over five years, DESRT is a component of the National Contaminated Sites Remediation Program. Objectives, priorities, and eligibility criteria for the program are presented, as are funding incentives. A brief review of DESRT projects underway is included, plus information on how to apply.

OVERVIEW OF THE DEVELOPMENT AND DEMONSTRATION OF SITE REMEDIATION TECHNOLOGY (DESRT) PROGRAM

1. Introduction

In October of 1989, the Canadian Council of Ministers of the Environment (CCME) initiated a plan of action to deal with high-risk contaminated sites by establishing the National Contaminated Sites Remediation Program (NCSRP). The program has three objectives:

i) based on the polluter pays principle, to identify, assess, and remediate, in a nationally consistent manner, all contaminated sites that are adversely affecting, or have the potential to adversely affect, human health or the environment;

ii) to provide the necessary government funds to remediate those contaminated sites (termed "orphan" sites) for which the owner or responsible party cannot be identified or is financially unable to carry out the necessary work; and

iii) to stimulate the development and demonstration of new and innovative remediation technologies.

The NCSRP operates on a cost-shared, five-year, $250 million budget based on matching funding by the federal government and the provincial/territorial governments. Of the total, $200 million will be directed to the remediation of orphan high-risk contaminated sites, and the remaining $50 million will be used to develop and demonstrate new remediation technologies under DESRT. In addition, the federal government has committed $25 million for the remediation of federal contaminated sites.

The program is administered mainly through bilateral agreements between the federal government and the provinces and territories. These agreements define administrative procedures and the role and responsibilities that each party has in cleaning up orphan sites and managing individual projects to develop and demonstrate technology. To date, such agreements have been signed with all provinces and territories except Saskatchewan, Manitoba and Yukon.

2. Orphan High Risk Contaminated Sites

Very briefly, orphan sites have been identified, and remediation projects initiated, in Alberta, Ontario, Quebec, Nova Scotia, and New Brunswick. In addition, two activities are underway in support of national consistency in dealing with contaminated sites in Canada.

The first is the development of a *National Site Classification System* for contaminated sites, a final report on which was released by CCME on March 18. This system is being used to designate contaminated sites into three broad categories of concern: high, medium, and low. A site is designated high-risk when site contamination is such that it represents a real or imminent threat to the environment. In this case, immediate action is required to reduce the threat.

The second activity is the development of *National Environmental Quality Criteria.* Interim criteria, released earlier this year, establish numerical limits for the assessment and remediation of soil and water based on the safe use of agricultural, residential and, parklands and commercial and industrial properties.

3. Technology Development and Demonstration

3.1 Objectives and Priorities

The principle objective of the DESRT component of the program is to accelerate the development of new and innovative technologies having the potential to resolve problems which are critical to the environmental remediation of contaminated sites. It covers the areas of site characterization, assessment, remediation, and compliance monitoring. The first priority is demonstration, over the medium term, of promising new technologies that have been developed to the pilot plant stage, but require on-site, field evaluation to verify performance and cost information. The second priority is to encourage the advancement of technologies that are in the laboratory stage of development, and offer alternative technologies for site remediation over the medium term.

3.2 Eligibility Criteria

The basic eligibility criteria are as follows:

- The technology must be unique, or used uniquely, and must have the potential for wide application at contaminated sites across Canada, or relate to a serious problem identified in an area within Canada.

- The project must involve technological risk, and should be designed to lead, ultimately, to commercialization of the technology.

- DESRT funding must bring incremental value to the project; if it would otherwise proceed at the same level of effort without DESRT assistance, the project is ineligible.

As this is a federal-provincial/territorial program, approval by both levels of government is required.

3.3 Financial Incentives

DESRT will share costs of the salaries of the project team, engineering and consulting services, special equipment and installation, start–up, monitoring and evaluation, equipment dismantling and clean–up, data quality assurance and quality control, economic assessment, and report preparation.

3.4 Projects Underway

Projects approved under the program are as follows:

British Columbia

The Pacific Place site in Vancouver is a proposed residential, commercial, and open space development of 82.5 hectares of land on the north side of False Creek in Vancouver. The site is contaminated with PAHs, other organics, metals, wood waste, and PCP. DESRT is participating in treatability studies involving innovative technologies for stabilization of organics and inorganics, bioremediation, and thermal extraction. These studies will be completed soon. Sandra Whiting of SCS Engineers will give a presentation on this project during session III tomorrow.

Alberta

The Peerless Wood Preservers site in Cayley is polluted primarily with PCPs. The R&D project under DESRT is to investigate the on-site land treatment of the contaminated soils, combined with in situ enhanced biodegradation in fractured till, and leachate capture in the underlying bedrock aquifer.

Located on the bank of the Bow River in the centre of Calgary, the Canada Creosote site is polluted with creosote and PCP as a result of wood preserving activities. There is a dense, non-aqueous phase liquid (DNAPL) pool within the gravel overlying bedrock under the site; drilling in the riverbed gravels of the Bow River showed DNAPL as well. Creosote can be seen on the river bed. Initial work under DESRT involves the development of technology for washing the riverbed gravel, allowing it to be replaced in the river. Colin Beresford of Acres International and Walter Ceroici of Alberta Environment will provide more details tomorrow, during session III.

Ontario

Two DESRT projects have been approved in Ontario. The first project is the third of a three-phase program to demonstrate, in an aquifer of low permeability, the *in situ* anaerobic biodegradation of chlorinated alkenes (for example, tetrachloroethylene) to non-toxic products. The first two phases involved field investigations into the geochemical and hydrogeological conditions at the site, located in North Toronto. The DESRT component will comprise testing laboratory observation and hypothesis in the field using *in situ* testers.

The objective of the second project is to demonstrate cost–effective technology for *in situ* and on–site bioremediation of soils contaminated with chlorinated phenols and PAHs, at the Domtar wood treatment site in Trenton. Allan Seech of Deerborn will be providing more details on this in session II.

New Brunswick

The Department of Transportation site in Saint John is contaminated with PCBs and heavy metals––mainly lead. The project under DESRT involves the investigation of soil washing/solvent extraction and bioslurry reactors for use in the treatment train. Maria Dober of Environment Canada will be presenting a paper on this project tomorrow morning.

3.5 How to Apply

It is suggested that those interested in applying for assistance under the program obtain a copy of the *Guidelines for Application to the DESRT Program*, available from:

DESRT Office
Technology Development Branch
Environment Canada
Unit 100, Asticou Centre
241 Cité des Jeunes Blvd.
Hull, Quebec
K1A 0H3

Tel: (819) 953–5228
Fax: (819) 953–4705

This guideline provides additional information, and includes a format for submissions.

NATIONAL CONTAMINATED SITES
REMEDIATION PROGRAM

OBJECTIVES

- APPLY POLLUTER PAYS PRINCIPLE TO CLEAN UP OF HIGH RISK CONTAMINATED SITES
- PROVIDE FUNDS TO REMEDIATE ORPHAN SITES
- DEVELOP & DEMONSTRATE NEW AND INNOVATIVE CLEAN-UP TECHNOLOGIES

ORPHAN HIGH RISK CONTAMINATED SITES

NATIONAL APPROACH

- NATIONAL SITE CLASSIFICATION SYSTEM
- NATIONAL ENVIRONMENTAL QUALITY CRITERIA

REMEDIATION PROJECTS INITIATED

- ALBERTA,
- ONTARIO
- QUEBEC
- NOVA SCOTIA
- NEW BRUNSWICK

DEVELOPMENT AND DEMONSTRATION OF SITE REMEDIATION TECHNOLOGY

(DESRT)

COVERS

- DEVELOPMENT (R&D) UP TO PILOT PLANT STAGE
- DEMONSTRATION UNDER FIELD CONDITIONS

OF NEW AND INNOVATIVE TECHNOLOGY FOR

- SITE CHARACTERIZATION
- SITE ASSESSMENT
- SITE REMEDIATION
- COMPLIANCE MONITORING

DESRT ELIGIBILITY CRITERIA

- TECHNOLOGY UNIQUE AND TRANSFERABLE
- TECHNOLOGICAL RISK AND COMMERCIALIZATION
- INCREMENTALITY

SHARED COSTS

- SALARIES OF PROJECT TEAM
- ENGINEERING & CONSULTING SERVICES
- SPECIAL EQUIPMENT & INSTALLATION
- QA/QC
- ECONOMIC ASSESSMENT & REPORT PREPARATION

DESRT PROJECTS UNDERWAY

BRITISH COLUMBIA

- PACIFIC PLACE

ALBERTA

- PEERLESS WOOD PRESERVERS
- CANADA CREOSOTE

ONTARIO

- *IN SITU* ANAEROBIC BIODEGRADATION OF CHLORINATED ALKENES
- BIOREMEDIATION OF SOILS CONTAMINATED WITH CHLORINATED PHENOLS AND PAH

NEW BRUNSWICK

- SAINT JOHN DEPARTMENT OF TRANSPORTATION SITE

HOW TO APPLY

GUIDELINES FOR APPLICATION TO THE DESRT PROGRAM

AVAILABLE FROM

DESRT OFFICE

TECHNOLOGY DEVELOPMENT BRANCH

ENVIRONMENT CANADA

(819) 953–5228

FAX (819) 953–4705

3.0

RESEARCH ACTIVITIES OF THE GROUNDWATER AND SOIL TASK FORCE OF THE CANADIAN PETROLEUM PRODUCTS INSTITUTE (CPPI)

BY

ADOLFO SILVA
CPPI
PETRO-CANADA INC.
CALGARY, ALBERTA.

CANADIAN PETROLEUM PRODUCTS INSTITUTE (CPPI)
SOIL AND GROUNDWATER ISSUE GROUP
(S&GIG)

- **ORGANIZATION**
- **MISSION/OBJECTIVES**
- **ISSUES/PRIORITIES**
- **WORK PLAN/ACCOMPLISHMENT**

Adolfo E. Silva
CPPI - S&GWIW

INITIALLY FORMED AT THE "WINNIPEG 1990 WORKSHOP"... IT DEVELOPED FROM A TASK FORCE INTO AN ISSUE GROUP...

- Formed in 1989 to organize national workshop... then asked to address
    - Technology Review
    - National Criteria
    - Field and Laboratory Protocols
    - Public Awareness and Education

- Initial mandate (task force) developed into a national activity to address soil and groundwater of the downstream petroleum industry.

- Work in coordination with four CPPI divisions to address the specific activities of regional interest (Western, Ontario, Quebec and Atlantic Regions).

- Included in our group are representatives of (8) oil companies, (4) CPPI divisions, CPPI - Ottawa Office, and we kept in close contact with other CPPI issue groups of interest to us, i.e. Health and Hygiene.

OUR MISSION: TO PLAY AN EXEMPLARY LEADERSHIP ROLE IN DEALING WITH S&GW ISSUES AFFECTING THE DOWNSTREAM PETROLEUM INDUSTRY....

- Enlarge the understanding and qualification of the issue.

- Encourage a consistent global and national approach to the soil and groundwater issue

  re:
  Technology
  Guidelines/Criteria
  Analytical Protocols
  Education - Awareness

- Addressing the issue with

  - a sound technical/scientifical approach
  - being environmentally responsible
  - a sound economic basis

- Maintain contact with CPA, API, GASReP and Environment Canada

THE ISSUES... THE SPECIFICS... THE PRIORITIES...

- Soil and groundwater contaminations arise from activities in the marketing and distribution, as well as refining.

- Some of the characteristics to consider,

    - Type of Contamination... light, heavy/weathered
    - Location/Urgency
    - Jurisdiction

- The priority is now... the issue will keep growing before it starts decreasing...

  Without considering recent announcement re sizing the business... we are facing a bill of approximately $500 M over the next five years.

CPPI S&GWIG WORK PLAN

- Review and Evaluation of Remediation Technologies
    - Soil Remediation
    - Groundwater
    - Treatment Centres
- Laboratory and Field Protocols
    - Analytical Techniques
    - Correlations
- Clean-up Criteria and Risk Assessment
    - Scientific Basis and Impact (CCME)
    - Environmental Impact of Contamination
    - Scope and Mechanics of Risk Assessment

CPPI S&GWIG WORK PLAN (continued)

- Issue Sizing
  - Internal Survey
- Information
  - Public Awareness and Education
- Technical Development
  - Reinjection of Off-Gasses
  - Bioreactor Treatment
  - Low Temperature Bioremedition
- Technical Positions Paper
  - Prevention and Minimization Program
  - Rehabilitation of Landfarms

SOIL TREATMENT CENTRES
A MEANS TO FACILITATE AND EXPEDITE SITE DECOMMISSIONING...

- "Soil Recycling Facility Standards" by Randall Warren

- Considered Across Canada: Atlantic Provinces, Quebec, Ontario, Manitoba, Alberta and British Columbia

- It seems simple... but need to consider

    - Guidelines and Regulations
    - Soil Handling, Transportation and Disposal
    - Treatment Facility Location, Design, Operation and Monitor

- Environmental and Economic Impact

    - Overall Operation
    - Sustainable Development

RECENT COMPLETED WORK AND REPORTS ISSUED...

REPORTS

• CPPI 91-9	"Manual of Petroleum Contaminated Soil Treatment Technologies" (available in French and English)
• PACE 90-3	"Weathering of Crude Oil in Surface Soils"
• CPPI 91-6	"In Situ Clean-Up of Benzene in Groundwater"
• In Preparation	"Impact of Oxygenated Fuels on Groundwater"
• In Preparation	"Regional Soil Recycling Facility Standards"

VIDEOS

• CPPI - 1991	"Soil and Groundwater Contamination By Petroleum Products"

TYPICAL ISSUES FACED WHEN DEALING WITH SOIL AND GROUNDWATER CONTAMINATIONS

- Guidelines/Criteria/Indicators
  - Scientific basis... how are determined?
  - Any consideration for natural phenomena (production and biodegradation)?
  - Validity of "total concentrations" (O&G, TPH, TEH)
    - i) Indicators vs Criteria
    - ii) Analytical Protocol
- Guidelines vs Analytical Techniques... Level of Confidence
  - How to consider variation in analysis...
  - Variability of the data... risk, analysis...
  - What is first... guidelines or analytical technique?
- Technical Data Evaluation
  - Risk analysis scope and procedure
  - ECO and/or Human toxicity

TYPICAL ISSUES FACED WHEN DEALING WITH SOIL AND GROUNDWATER CONTAMINATIONS (continued)

- Environmental Approach... Sustainable Development
  - Global Approach... soil, water, air, hygiene
  - Environmentally Responsible
    i) Technology Impact
    ii) Product Impact
  - Economic Impact
    i) Technology Selection
    ii) Clean-Up Level

4.0

CANADIAN PETROLEUM ASSOCIATION ENVIRONMENTAL RESEARCH ADVISORY COUNCIL OVERVIEW OF RESEARCH ACTIVITIES

BY
GEORGE COLLIN
AMOCO CANADA PETROLEUM COMPANY LTD
CHAIRMAN - CPA/ERAC

Canadian Petroleum Association
Environmental Research Advisory Council:

Research Priorities & Activities

GASREP/DESRT 2nd Annual Symposium
On Groundwater and Soil Remediation

Presented By:

George Collin
Amoco Canada Petroleum Company Ltd.
Chairman - CPA/ERAC

Canadian Petroleum Association Members

- Makes about two-thirds of all upstream petroleum industry expenditures in Canada

- Produce about 80% of Canada's crude oil and 70% of it's natural gas

Vision

CPA Member Companies will be Environmental Leaders in Canada, Recognized for Their Contribution to a Healthy Environment.

Mission

To Provide Leadership in Managing the Environmental Business of the Canadian Petroleum Association

CPA - ENVIRONMENTAL RESEARCH ADVISORY COUNCIL

MISSION STATEMENT

CPA's Environmental Research Advisory Council will identify, initiate and manage environmental research in coordination and cooperation with government, academia and the public for Western Canada's upstream petroleum industry, for the benefit of the environment.

CPA-ERAC VISION STATEMENT

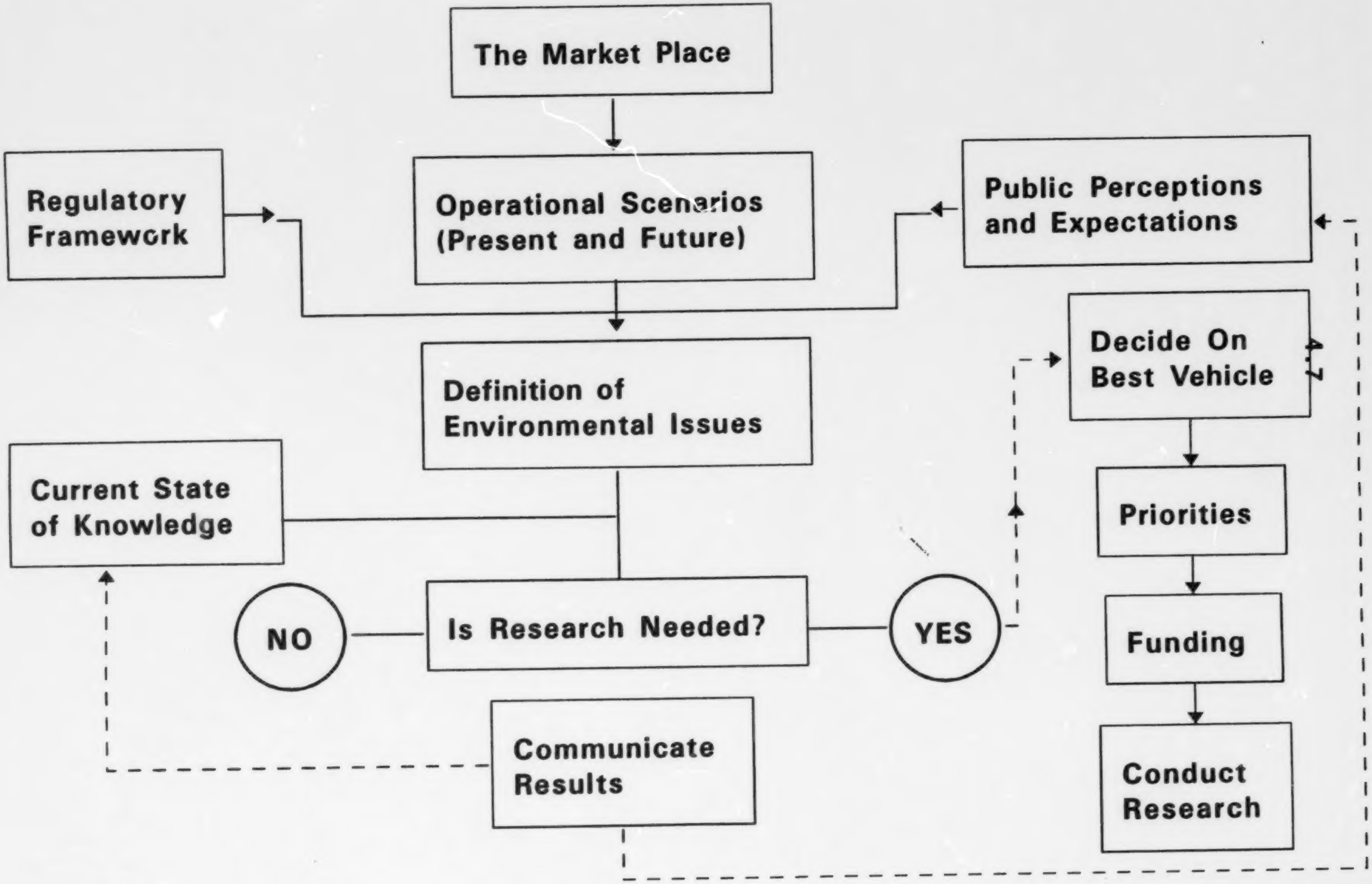
The Environmental Research Advisory Council within CPA will be:

1. Responsible for environmental research on upstream oil and gas exploration and production for Western Canada's operations.
2. A Joint industry-government supported research group with adequate funding.
3. A recognized leader of oil and gas environmental research.
4. Recognized for scientific credibility.

ERAC Steering Committee Members:

- CPA Member Company Representatives
- Alberta Energy Resources Conservation Board
- Alberta Environment
- Alberta Forestry, Lands and Wildlife
- Environment Canada
- Alberta Research Council
- Alberta Environment Center
- Saskatchewan Research Council

CPA Environmental Research - Program Definition



The Market Place

Regulatory Framework

Operational Scenarios (Present and Future)

Public Perceptions and Expectations

Definition of Environmental Issues

Current State of Knowledge

Is Research Needed?

NO

YES

Decide On Best Vehicle

Priorities

Funding

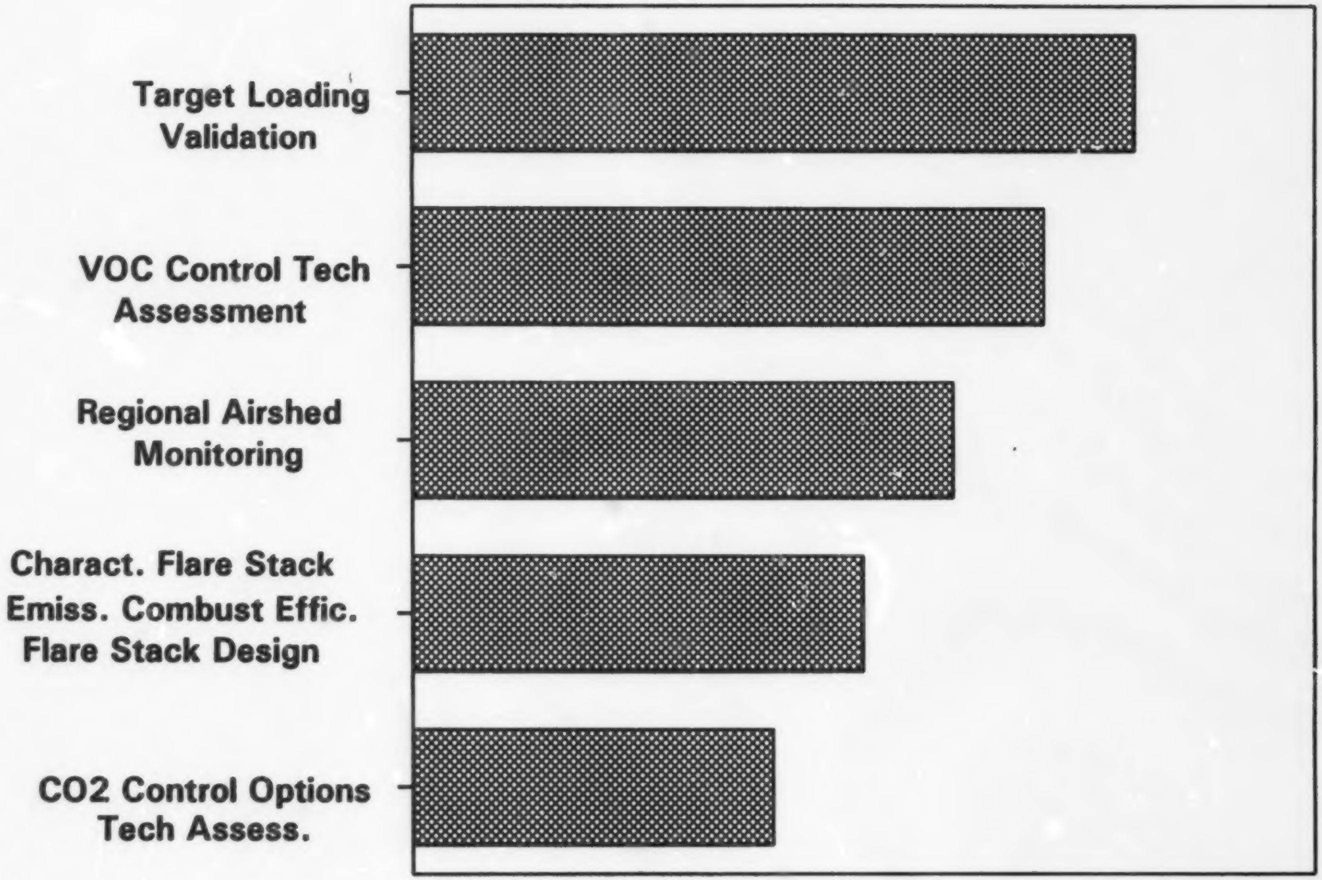
Conduct Research

Communicate Results

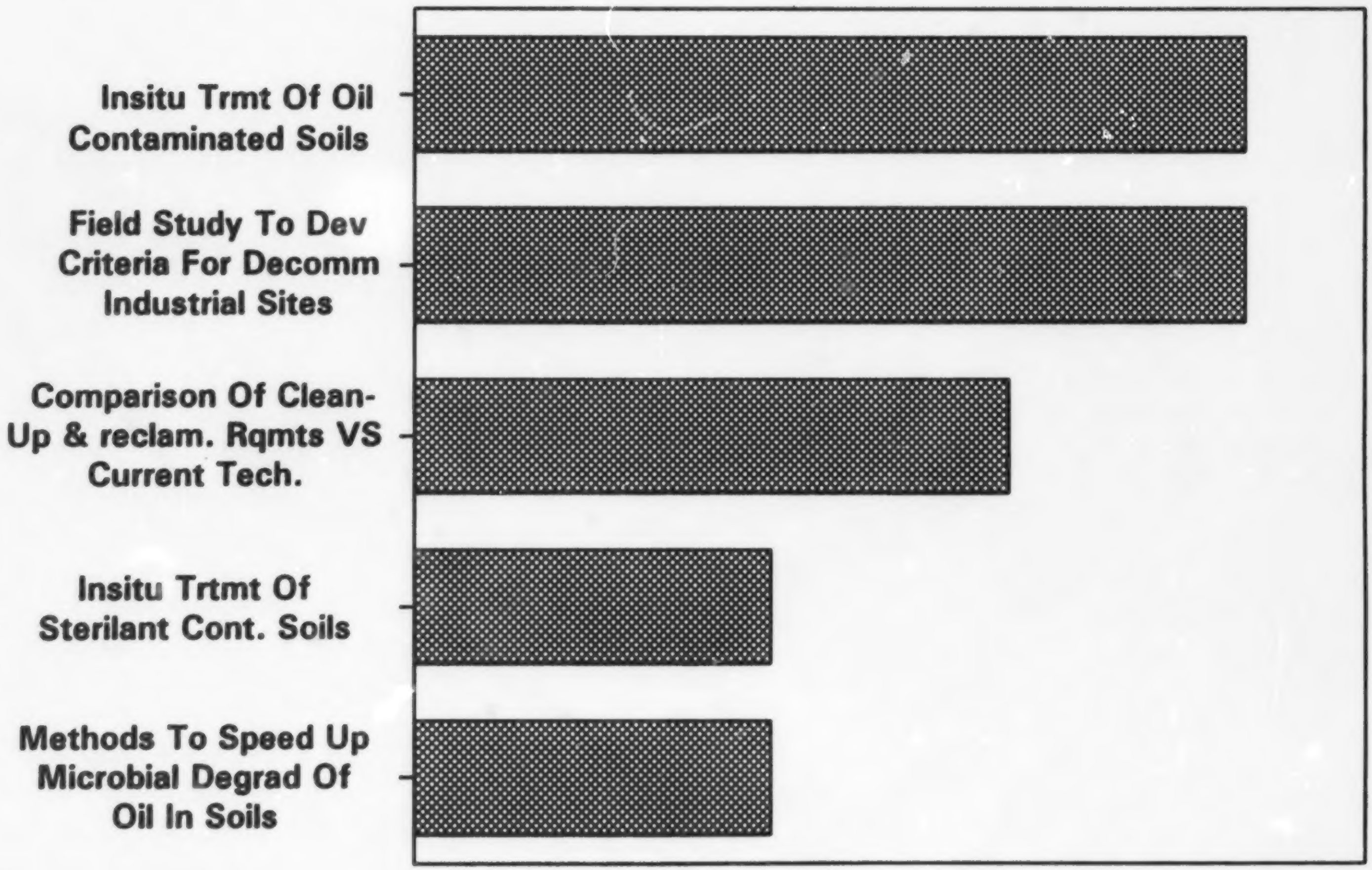
CPA - ERAC Research Priorities:

- Annual Multi-stakeholder Priority Setting Workshop
- 5 Priority Subject Areas - Water, Waste, Air, Land, Biological
- 41 Specific Research Topics Proposed;
  9 High Priority Research Areas Selected By Steering Committee
- Based on Steering Committee's Recommendations 1992 Research Focus Is On:
  - Groundwater
  - Waste Treatment
  - Air Emissions
  - Effluent Toxicity

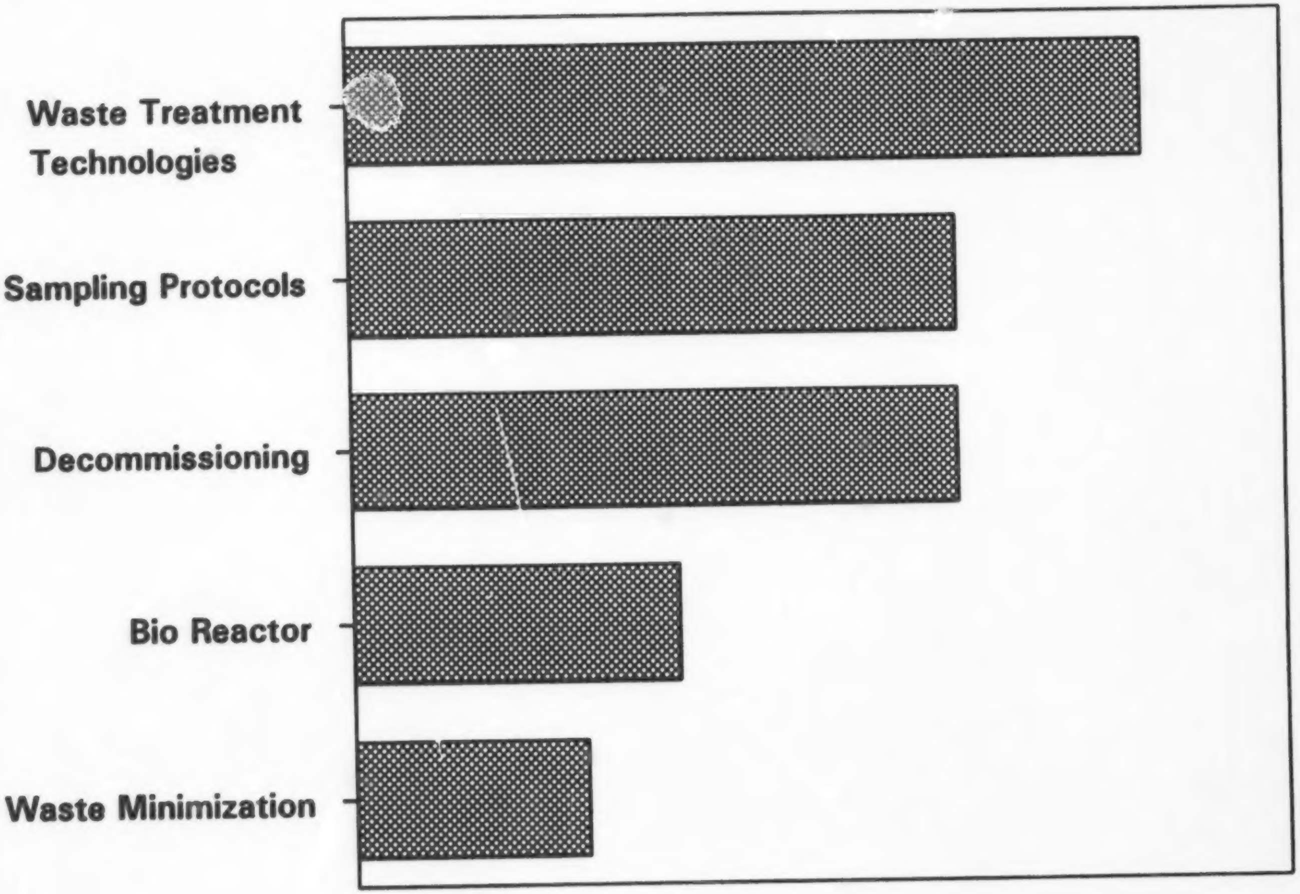
AIR PRIORITIES



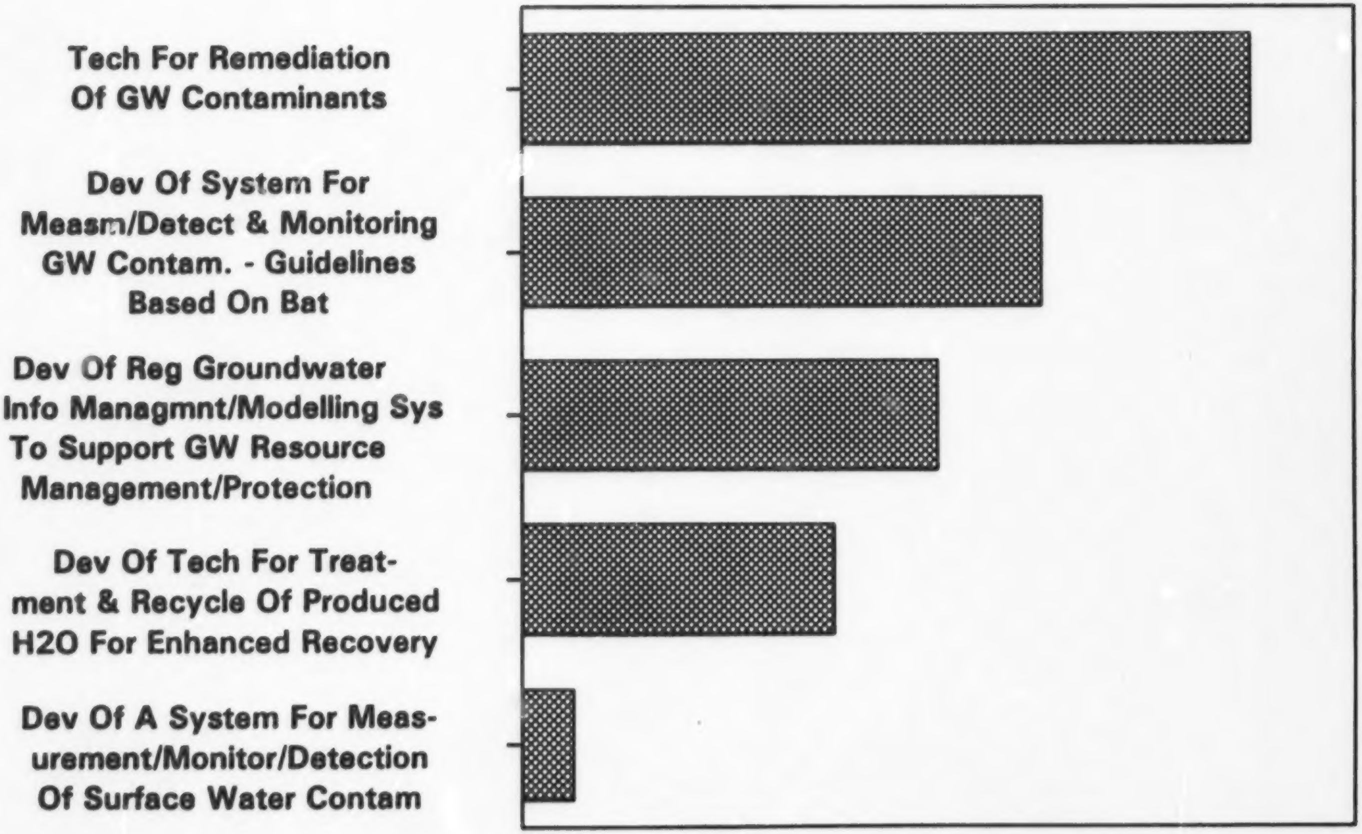
LAND PROJECTS PRIORITIES



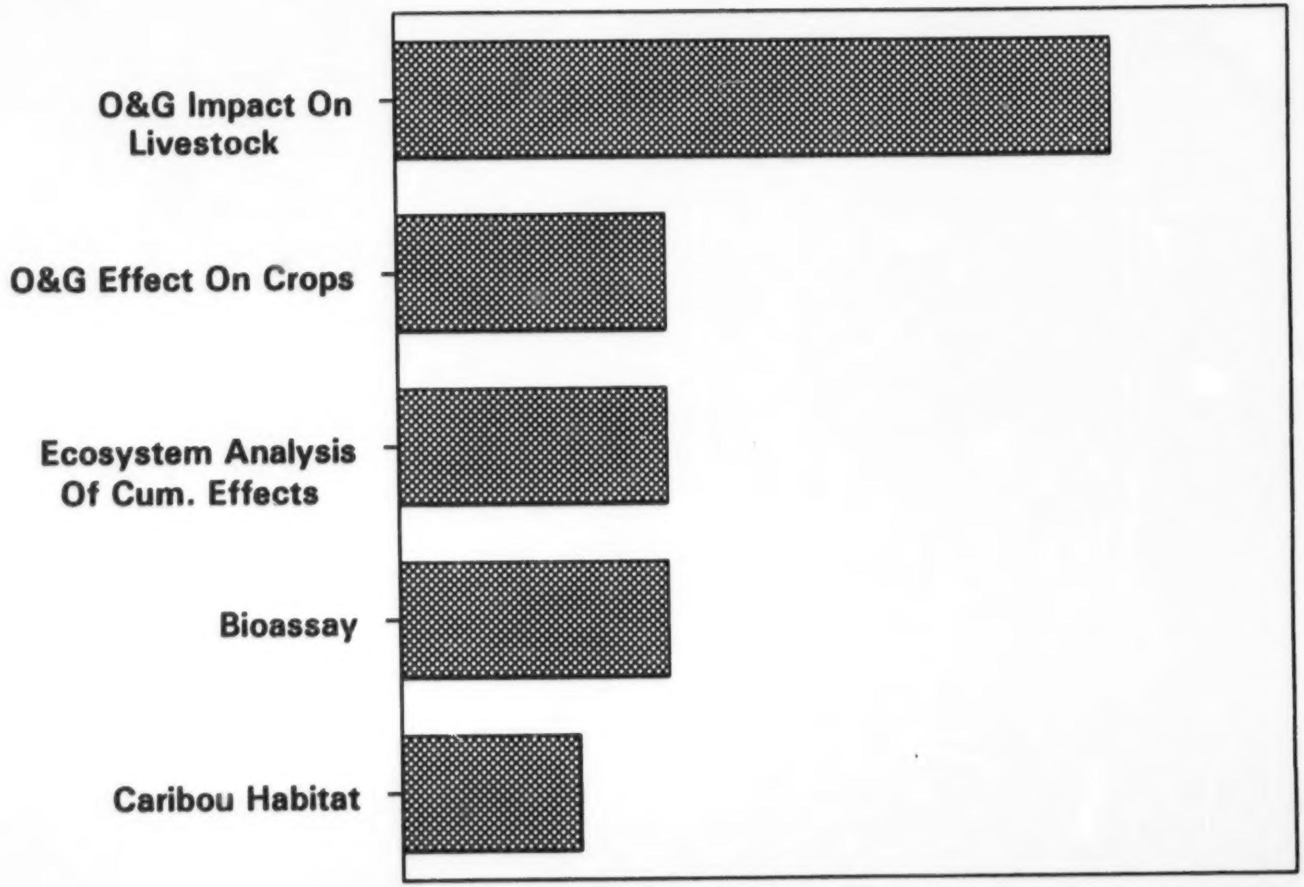
WASTE PRIORITIES



WATER PRIORITIES



BIOLOGICAL PRIORITIES



CPA - ERAC 1992 Research Work Plan

- Finalization of Research Reports From 1991 Research

- Continuation With 3 Ongoing Projects:
  - Investigations of flare gas emissions in Alberta
  - Development of a Surface Bioreactor
  - Assessment of the impact of sulphur dust and lime on lodgepole pine fores

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CPA - ERAC 1992 Research Work Plan

Continued

- Three New Projects:
  - Field demonstration of treatment technologies for remediation of subsurface contamination around sour gas plants
  - Development of a groundwater information management and modeling system
  - Development of a new biological test for organic toxicity testing of industry effluents

5.0

OVERVIEW OF SOIL AND GROUNDWATER RESEARCH ACTIVITIES OF THE AMERICAN PETROLEUM INSTITUTE (API)

BY

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WASHINGTON, D.C.

OVERVIEW OF SOIL AND GROUNDWATER RESEARCH ACTIVITIES OF THE AMERICAN PETROLEUM INSTITUTE

Bruce Bauman, API Health and Environmental Sciences Dept.

The American Petroleum Institute is a trade association for the domestic petroleum industry in the United States, with over 200 corporate members and 5000 individual members. Subsurface research activities are managed by the API Soil / Groundwater Technical Task Force, a committee made up of over 25 member company engineers, hydrogeologists, soil scientists and chemists representing both the research and operations sectors of the petroleum industry. The research areas of this group have been divided into five principle areas: Biodegradation Processes, Fate and Transport, Remediation, Decision Making Tools for Remediation, and Detection / Analytical Methods. A summary of each of the current projects in these subject areas follows.

BIODEGRADATION PROCESSES

TECHNOLOGY REVIEW UPDATE: IN-SITU AND ON-SITE BIOREMEDIATION OF REFINED AND FUEL OILS

OBJECTIVE: To provide a concise summary of the literature for the period 1988 to present that addresses topics of significance to the biodegradation of petroleum hydrocarbons in soil and groundwater.

STATUS: This study will produce a literature review (1988–1911) of recent scientific studies addressing the biodegradation of petroleum hydrocarbons (e.g., crude oils, fuels, and lubricants) in soil and groundwater. Two separate work products will be delivered: 1) a written report summarizing recent literature if interest, and 2) a computerized database of the bibliography. Besides its value as a compilation of current knowledge, the report will be structured to help identify those topics of importance where further research is needed, and to the extent practicable, to serve as an educational document that helps the "nonexpert" understand the basic physical, chemical, and biological principles that influence the subsurface hydrocarbon biodegradation. The study will be managed under a joint project team of members from the API Soil/Groundwater Technical Task Force and the Benzene Biodegradation Workgroup. This study will complement a recently completed literature review of this subject by the U.S. Navy that covers literature through 1987. This document will serve as a valuable reference for practicing environmental professionals (both industry and regulatory) to help them evaluate the applicability of bioremediation at contaminated sites. It will also be an educational tool for those who are new to the field.

ANALYSIS OF FATE AND TRANSPORT OF SOLUBLE HYDROCARBON PLUMES

OBJECTIVE: Develop procedures for the design of field monitoring programs to demonstrate passive biodegradation of soluble hydrocarbon plumes, and to develop a groundwater transport model that accurately characterizes the process of mixing oxygen and dissolved hydrocarbons at the plume edges.

STATUS: The contractor will coordinate his efforts with the activities of the passive biodegradation studies (GW-25A/B) to help devise an approach to designing field monitoring programs that demonstrate the nature of passive biodegradation at product spill sites. Using the random walk approach, a 3-D transport model will be developed that uses new information for characterizing the nature of hydrocarbon/oxygen mixing at plume edges, and that also adequately accounts for the heterogeneity inherent in groundwater systems. The contractor will also examine the potential for simplifying the model to 2-D, using vertical averaging. The model will be run to help determine the monitoring design for two current passive biodegradation studies, and to help evaluate the behavior of the soluble plume at both sites. Draft report due February 1993. The model developed will be useful for site-specific evaluations of the potential off-site impacts from petroleum spills. It should lead to shorter and less expensive cleanups at some sites. It will further demonstrate our understanding of the processes influencing aerobic biodegradation, and help to increase the likelihood that such processes will become incorporated into EPA regulatory models.

CHARACTERIZATION OF THE NATURAL ATTENUATION PROCESS AT A HEATING OIL SPILL

OBJECTIVE: Characterize the natural rate of biodegradation of a residential heating oil UST spill and assess its ability to contain the dissolved organic groundwater plume.

STATUS: Limited soil and groundwater contamination by a leak from a heating oil UST has been characterized at a residential site in North Carolina. Additional hydrogeological measurements will be made over a 12-month period to assess the potential for off-site migration of dissolved organics. Particular attention will be paid to those parameters that may indicate the occurrence of natural biodegradation (e.g., dissolved oxygen depletion and carbon dioxide production). Modeling will be used to predict the rates of biodegradation and determine if a steady-state condition has been reached that will naturally contain the dissolved contaminant plume. Monitor site quarterly in 1992; assemble and summarize data for draft report in February 1993; final report due in June 1993. This study will help to further document the phenomenon of natural or "passive" biodegradation as a means for containing contamination from UST spills. It will provide valuable knowledge of the behavior of distillate fuel spills. Such information will lead to less sever requirements for closure at groundwater remediation sites, and allow more rapid and less expensive cleanups.

SUBSURFACE MONITORING DATA FOR ASSESSING IN-SITU BIODEGRADATION OF AROMATIC HYDROCARBONS (BTEX) IN GROUNDWATER

OBJECTIVE: Demonstrate that field measurement methods can be used to determine rates of BTEX biodegradation in dissolved groundwater plumes so that regulatory permission can be obtained for "passive" bioremediation at fuel spill sites.

STATUS: Two gasoline spill sites will be identified and characterized for pertinent chemical and physical properties. Groundwater and soil gas samples will be obtained on a monthly basis and analyzed for key inorganic and organic parameters (e.g., CO_2, O_2, BTEX, etc.) for 18 months. The indirect measurements of subsurface biological activity will be compared with predicted movement of BTEX in the dissolved plume to see if they provide reasonable estimates of natural biodegradation rates of BTEX in groundwater. Laboratory leaching studies and microcosm biodegradation studies will be conducted to complement the field study. Several modeling approaches will be evaluated for their ability to successfully predict rates of natural attenuation of BTEX. Delays have been encountered in finding adequate sites to conduct the field research in both North Carolina and Texas.

NCSU: Initial characterization of the field site has been completed, and a draft report was submitted in mid-September. A decision will be made in October regarding the suitability of this site in terms of the study objectives. Possible alternative sites have been identified.

Rice: Site selection has been narrowed to two sites. A final decision will be made in October whether to use one of those sites or to continue looking. Results will be used to document the capability of natural biodegradation processes to stabilize dissolved contaminant plumes from spill sites. This should lead to lower cleanup costs.

MODELING OXYGEN TRANSPORT-LIMITED BIODEGRADATION IN GROUNDWATER

OBJECTIVE: To provide an improved ability to accurately model the biodegradation of benzene and other soluble hydrocarbons in groundwater.

STATUS: The study will begin with a literature review of field and laboratory biodegradation rate data for petroleum hydrocarbons in groundwater, including information on dissolved oxygen concentrations, groundwater temperature, aquifer characteristics, and contaminant concentrations. This information will be used to help develop and verify a three-dimensional numerical model that will predict oxygen-limited biodegradation rates of soluble hydrocarbon plumes into heterogeneous groundwater systems and the role of oxygen transport in the biodegradation process. The initial literature review has been evaluated but will not be finalized until project completion to allow continual updating as relevant research is published. Most work has been completed on the numerical and analytical solutions developed in Phase II. Further Phase III work on the Cray computer simulations will evaluate alternative contamination scenarios and will also compare the results obtained in the heterogeneous simulation with those from a homogeneous simulation that uses the macrodispersion coefficients developed in Phase II. The draft final report has been reviewed and comments returned to the contractor. Further work on this topic is under consideration. Results will be used to improve the ability of existing, more simple biodegradation models to adequately account for the influences of small-scale aquifer heterogeneity on aerobic biodegradation rates. It is hoped that this research will increase the likelihood that EPA will include aerobic biodegradation processes in its regulatory models.

PHASE I—THE ANAEROBIC DECOMPOSITION OF BENZENE IN ANOXIC AQUIFER SLURRIES: AN EVALUATION OF THE EPA OFFICE OF SOLID WASTE PROTOCOL FOR ANAEROBIC BIODEGRADATION TESTING

OBJECTIVE: To evaluate the new EPA anaerobic biodegradation protocol and assess the potential for anaerobic biodegradation of benzene in groundwater.

STATUS: Most of the study's budget was directed toward a critical assessment of the EPA biodegradation protocol (which has not been performed since its promulgation in 1988). Important products include suggestions on improvements in the protocol that may be required and, perhaps more importantly, rates of anaerobic benzene biodegradation. Whereas the full protocol calls for obtaining samples from six different sites, only one site was evaluated in this study; future sites will also be evaluated pending the results of this work. Aquifer microcosms were constructed from field samples and carefully monitored for up to 64 weeks. Further, an alternative method for monitoring biodegradation in anaerobic microcosms was investigated. This project will provide valuable information on benzene biodegradation rates in groundwater, both aerobic and anaerobic. To date, the following progress has been made toward completion of the original proposal:

1. Evaluation of the EPA protocol (i.e., critical evaluation of its practicality and implementabilty) is complete. Numerous problems in the execution of the protocol were noted and alternatives suggested/implemented.
2. Evaluation of an alternative method for monitoring the microcosms is also complete and shows that the method (using pressure transducers to provide continuous monitoring) is effective. A meeting with the EPA authors of the protocol was held in March 1991 to present these results. EPA has stated its intention to redraft the protocol, incorporating API research results where appropriate.

A draft report on tasks 1 and 2 above is being prepared for publication. Results will be used to document shortcomings in the EPA's anaerobic biodegradation protocol to encourage protocol modification. This will allow the industry to use the protocol to generate quality data on the anaerobic biodegradability of various organic compounds.

PHASE II—THE ANAEROBIC DECOMPOSITION OF BENZENE IN ANOXIC AQUIFER SLURRIES

OBJECTIVE: Generate anaerobic biodegradation rate data for gasoline and diesel components, characterize low-oxygen-concentration BTEX biodegradation, and continue monitoring anaerobic biodegradation of benzene (EPA protocol).

STATUS: This work is both a continuation of work initiated in 1989 and the start of new studies on the anaerobic biodegradation of gasoline components other than BTEX. Building on the 1990 work of anaerobic benzene biodegradation, it is anticipated that an additional site will be identified and sampled and microcosms established and monitored for at least 64 weeks. Studies on the aerobic biodegradation of BTEX at low-oxygen concentrations will also be completed. Samples have been obtained and microcosms established for the study to assess benzene biodegradation at low (<2 ppm) oxygen concentrations. The experimental work will be completed by December 1991.

The project team has selected more than 50 constituents of gasoline and diesel fuels whose anaerobic biodegradability will be evaluated during 1992. Field sampling for microcosm materials was conducted in early September. Monitoring of the anaerobic benzene biodegradation microcosms (EPA /TSCA protocol) continues. No anaerobic losses have been observed. A second sampling site for this protocol has not yet been identified. Results will be used to provide EPA with rates of anaerobic BTEX biodegradation in groundwater, which can then be used in EPA's regulatory contaminant fate and transport models. This information will also be useful for general models that include biodegradation.

REMEDIATION

AN EVALUATION OF ON-SITE SOIL TREATMENT TECHNOLOGIES

OBJECTIVE: To compare the effectiveness of existing on-site remediation technologies for soils contaminated with mid- and light-boiling hydrocarbons.

STATUS: This multiphase project entails a review and selection of approximately three on-site soil remediation technologies for an actual field demonstration of their effectiveness at an inactive Chevron fuel terminal in Tacoma, WA. The 3-acre site will be fully characterized for variations in hydrocarbon concentrations in the soil and subsurface matrix differences. Using a randomized block design, soil plots will be assigned to each technology for decontamination. Both total petroleum hydrocarbons and selected hydrocarbon indicator constituents will be monitored for treatment effectiveness. The contractor has initiated a review of published information on currently available soil cleanup technologies and has completed the site characterization task. An engineering assessment of potentially useful technologies for selection as candidates for on-site hydrocarbon decontamination identified eight different bioremediation methods and two thermal treatment methods for evaluation. Three control plots have also been established and soil samples taken at the beginning of treatment, at intervals during treatment, and at the completion of the treatment method to assess the effectiveness for removing BTEX and selected PNAs from soils. Final samples on biodegradation plots were taken in August. The draft final report is expected in November. Results will provide a comparison of effectiveness of different soil treatment techniques, which will enable users to evaluate the applicability of these types of remediation methods for their site(s). Results should also be effective in helping to convince regulatory officials that such methods can be used effectively.

SOIL TREATMENT OF GASOLINE-CONTAMINATED GROUNDWATER BY SURFACE APPLICATION

OBJECTIVE: To evaluate land application as a potential treatment technology for hydrocarbon-contaminated groundwater from gasoline spill sites.

STATUS: Field and laboratory studies document the sorption, volatilization, and biodegradation of BTEX in water during steady-state infiltration after application to the soil surface. Data collected were used to develop and validate a numerical model of these processes. This work is a follow-up to a previous field study that showed promising results (Removal of Soluble Petroleum Constituents through Soil Application Rehabilitation of Groundwater, API Publication No. 4475). Initial laboratory studies have been completed, and the modeling approaches have been worked out. Further laboratory studies are continuing. The field site has been instrumented and its hydraulic properties characterized. Field tests have been conducted that compare the effects of different loading rates, BTEX concentrations, and water delivery methods. Draft final reports on the laboratory and field studies have been submitted are are currently under review. A draft final report on modeling studies is anticipated by December. Enable remedial design engineers to better evaluate in situ biological treatment as a candidate technology for remediation of gasoline- contaminated groundwater. The study will provide remedial system engineers with the approach and pertinent data for design of a full-scale in situ system.

FIELD EVALUATION OF SOIL VENTING

OBJECTIVE: To investigate the ability of in situ soil venting to remove soluble hydrocarbons to the extent that residual levels will not adversely affect groundwater.

STATUS: The contractor will conduct in situ venting of petroleum hydrocarbons at two field sites in California. The characteristics of the two sites are sufficiently different that review of engineering parameters used and the results obtained will be used to predict the effectiveness of this technology at other sites. Treatment will be continued until results of soil bore leachate tests indicated that hydrocarbon removal efficiency has reached a plateau. A venting program has been completed at one site; results showed that significant reduction of aromatic hydrocarbons can be expected. Work is also complete at a former retail facility in Fullerton that was selected as the second site. A draft final report that includes the results from both sites is due in October 1991. Study findings will provide remedial design engineers with field performance data for soil venting systems by which the effectiveness of this technology can be evaluated. These findings will assist the remedial design engineer in determining whether soil venting should be considered as a candidate technology for site-specific treatability analysis.

FATE AND TRANSPORT RESEARCH

CHEMICAL FATE AND TRANSPORT OF OXYGENATES IN GROUNDWATER

OBJECTIVE: To evaluate the impact of oxygenates in gasoline on the fate and transport of benzene, toluene, ethylbenzene, and xylene (BTEX) in groundwater.

STATUS: Blends of gasoline and varying amounts of MTBE and methanol were evaluated in the laboratory to determine oxygenate effects on aqueous solubility, sorptive retardation, and biodegradation of BTEX. In a field study, the fate and transport of contaminated groundwater plumes using gasoline, a methanol/gasoline mixture (85% methanol/15% gasoline), and a 15% MTBE fuel were compared. The final report for the laboratory cosolubility study, Chemical Fate and Impact of Oxygenates in Groundwater: Solubility of BTEX from Gasoline–Oxygenate Mixtures (API Publication No. 4531), is available from API Publications Distribution. The BTEX cosolubility effect of methanol was observed when water was contacted with gasoline containing high (>50%) methanol content, but only at high gasoline:water phase ratios (>10:1). No cosolvency effect was observed with gasoline containing MTBE. Simulation of the resultant dissolved BTEX plume from a spill of gasoline with a high-methanol content suggests that higher BTEX concentrations than from a pure gasoline spill would be expected at the front edge of the plume where dissolved methanol concentrations would be high.

Findings of the biodegradation and sorption studies have been reviewed and will be incorporated as appendices to the final report on the field study. The initial draft of the field study report is expected in October. Provide insight into the transport and fate of BTEX from spills of oxygenated fuels to groundwater. This insight will enable more cost-effective site characterization and remedial system design.

MEASUREMENT OF MOTOR-FUEL-CONTAMINATED SOIL LEACHATE

OBJECTIVE: To develop a standard leaching protocol for use in assessing the potential for groundwater contamination from motor-fuel-contaminated soils.

STATUS: Phase I will evaluate different methodologies for characterizing the leaching of hydrocarbon from contaminated soil using column studies, TCLP, and modified TCLP batch extraction procedures. Three different soil types (sandy, silty, and clayey) will be screened. Focus is on soils that have been treated (e.g., vacuum extraction and bioremediation) or that have low levels of residual contamination (e.g., <1000 ppm TPH). Soils and leachate will be analyzed for BTEX, MTBE, and other hydrocarbons. Correlations between soil contaminant concentrations and leachate contaminant concentrations will be made. Soil samples will also be characterized by field analytical methods (e.g., soil headspace) and results correlated with leachate concentrations. A recommendation for a standard leachate generation and characterization protocol will be developed to evaluate several additional soils. Further studies of as many as 40 more sites are being considered for Phase II (1991 funds). Results from Phase II should provide guidance for the determination of soil cleanup standards. An interim report of Phase I progress has been received and reviewed. Batch leaching studies have been completed for two soils, which show that soluble organics in leachate are predictable based on the liquid-to-soil ratio, and that the length of extraction does not significantly affect leachate concentration. Correlations have also been observed between the batch leaching results and the soil column leaching studies. Work on a third soil is nearing completion, and a field soil will be evaluated in a similar fashion. A draft report on Phase I work is expected by the end of October, and Phase II work is scheduled to begin at that time. Results will be used to characterize the range of contaminant concentrations that may leach from different soils, which should lead to more reasonable cleanup standards for contaminated soils.

MEASUREMENT OF MOTOR-FUEL-CONTAMINATED SOIL LEACHATE (PHASE II)

OBJECTIVE: Develop standard leaching and field protocols for assessing the potential for groundwater impacts from fuel-contaminated soils; develop a database of soil leachate concentrations.

STATUS: The contractor will perform the standard laboratory leaching protocol (developed during Phase I) on 20 or more contaminated soils from actual UST sites to determine the range of BTEX concentrations and other soluble organics that may leach from contaminated soils. Various headspace and solvent extractions of these same soils will be performed to assess the correlation of simple field and lab test results with the leaching tests. Will begin in early 1992 pending review of Phase I report. The lab and field methods developed in this study will be used to provide improved, cost-effective estimates of potential groundwater impacts from contaminated soils that have been treated or that have lower levels of hydrocarbons.

SUBSURFACE TRANSPORT OF NON-BTEX PETROLEUM CONSTITUENTS

OBJECTIVE: To identify petroleum product constituents that are of concern when released to the subsurface environment, and to assess their fate and transport behavior in soil and groundwater.

STATUS: The contractor will conduct a literature review to (1) identify non-BTEX compounds of concern when released to the subsurface environment, and (2) summarize current knowledge of the physical/chemical properties and subsurface fate and transport of these compounds of concern. The compounds of concern will be selected based on toxicity, prevalence in petroleum products (product composition), mobility in the subsurface environment, and current/future level of regulatory emphasis.

Phase II—As part of the Phase I literature survey, the contractor is to identify significant gaps in the state of research on the subsurface fate and transport of the compounds of concern and practical and meaningful research alternatives to address these gaps. In Phase II, the contractor will conduct one of these proposed research alternatives. Phase I — Literature review and bibliography due September 1992; Research plan for Phase II due November 1992; Phase II research report due February 1993. The findings of this research will enable API member companies to (1) better understand the fate and transport behavior of selected non-BTEX compounds in the subsurface environment, (2) develop and negotiate meaningful environmental cleanup criteria for these compounds, and (3) conceive, develop, and implement containment and remedial options for these compounds.

OXYGENATED FUEL DISSOLUTION, PLUME CHARACTERISTICS, AND SOIL INTERACTIONS

OBJECTIVE: To generate laboratory data regarding the nature of groundwater contamination plumes likely to be created from leaks and spills of oxygenated fuels.

STATUS: In soil column studies, the partitioning of methanol and gasoline into water, simulating an M-85 spill, will be evaluated. The distribution of BTEX among the aqueous, methanol, and gasoline phases will be evaluated in batch experiments. Studies using a thin layer of sand between two parallel glass plates will provide visual confirmation of methanol/gasoline interactions with water. Additional work will be performed to characterize the surface tension relationships between methanol/water mixtures and air. Laboratory work was completed in September 1991, and a draft final report will be submitted by December 1991. June 1992

Results will be used to predict the behavior of M-85 spills to groundwater so that their environmental impact can be compared with that of gasoline spills.

DECISION MAKING TOOLS FOR REMEDIATION

TECHNOLOGY LIMIT AS ALTERNATIVE TO GROUNDWATER CLEANUP STANDARD

OBJECTIVE: To determine if statistical methods can determine from monitoring data the practical limit of the in-place remediation technology.

STATUS: Phase I—The contractor performed a statistical evaluation of groundwater monitoring data from spill sites undergoing remediation. Two regression methods were evaluated to determine if they would be effective in identifying a limit beyond which further remediation by the in-place technology is impractical. The contractor will also provide information on analytical variability and site factors (e.g., natural attenuation) as added arguments for reassessing the effectiveness of the current remedial design. Phase II—Since several states are adopting the asymptotic limit concept for assessing the effectiveness of ongoing cleanup programs for USTs and are amenable to alternative cleanup goals on a site-specific basis, a stand- alone, PC-compatible software package will be developed. The stand-alone, PC-compatible software package will allow users to regress site data by four methods: linear, linear asymptotic, exponential (zero asymptote), and nonlinear (nonzero asymptote). Comparison of regression results by the four methods will allow users to determine whether site data are following an asymptotic trend, and if so, when the asymptotic region has been attained.

The software users' manual will detail the technical basis of each regression method and the proper interpretation of regression results as well as provide guidance on the operation of the software itself. Phase I—The contractor has completed the statistical evaluation of the site monitoring data and analyzed some of the factors affecting variability and its impact on determining the asymptotic limit. The effectiveness of both linear and exponential approaches was evaluated. The final report, Technological Limits of Groundwater Remediation: A Statistical Evaluation (API Publication No. 4510) is available from API Publications Distribution. Phase II—The beta test version and first draft of the user's manual are currently being reviewed. Submission of final software and manual is anticipated in October. The statistical evaluation techniques will enable member companies to identify the practical limits to site remediation by pump-and-treat and/or in situ treatment technologies. The techniques will allow member companies to better determine when site conditions warrant reassessment of the continued effectiveness of existing remedial technologies. The PC software will enable member companies to better encourage dissemination of the asymptotic concept to users and regulators.

SCREENING MODELS FOR THE LAND DISPOSAL OF E&P WASTES

OBJECTIVE: To develop a procedure for generating waste component concentration limits for use as guidance to states or industry in conducting environmentally protective practices for managing and disposing exploration and production (E&P) wastes.

STATUS: This 2-year study will consist of modeling the transport and fate of soluble constituents found in land-disposed E&P wastes. In 1990 (Phase I), the contractor performed a literature review on information and methods for assessing salt and oil impacts on groundwater, selected and made modifications to model(s) applicable to the range of constituents of interest, and validated the model(s) using existing laboratory and field data. In 1991 (Phase II), the contractor will make refinements to the model(s) to account for ion exchange, oxygen transport, aerobic degradation parameters, and subsurface heterogeneities and will integrate the handling of these functions into an efficient and user-friendly package. A draft final report on Phases I and II is due in December 1991. Results are to be used to help develop guidance for the disposal/treatment of wastes at E&P sites (i.e., will be used in formulating waste management guidelines contained in the Production Department's "API Environmental Guidance Document").

DEVELOPMENT OF WASTE AND DISPOSAL PRACTICE-SPECIFIC GROUNDWATER MODELS

OBJECTIVE: To provide API with documentation on the impropriety of the EPA Toxicity Characteristic Rule for wastewaters managed in surface impoundments, and to demonstrate that EPA should consider specific modeling scenarios for certain large-volume waste management practices (including nonhazardous waste impoundments).

STATUS: Phase I will evaluate EPA's comparison of the dilution/attenuation factors (DAFs) developed for the Toxicity Characteristic Rule (focusing on benzene) using the EPACML and EPACMS models, including the modeling assumptions used, and validate the input data. In Phase II, the contractor will conduct a survey of petroleum industry surface impoundments to develop a hydrogeologic database that can be used as more realistic input to these models to provide a better estimate of potential exposures to contaminants released from surface impoundments. The draft report on Phases I and II is currently under review by the project team. Several important assumptions of the EPACML model that are poorly applied to the surface impoundment scenario have been identified (e.g., continuous operation, steady state) and evaluated. A sensitivity analysis showed significant impact on the calculation of the dilution attenuation factor. During Phase II, data from 82 surface impoundments at refineries were collected and statistically analyzed to develop some of the parameter distributions required as input into the EPACML model. An alternative modeling scenario was developed using parameter distributions from the surface impoundment database for infiltration rate, area of impoundment, and distance to receptor well. The DAF for the preliminary alternative modeling scenario was five times greater than the DAF calculated in EPA's scenario for the sandy loam soil cover/unsaturated zone environments. Results will be used to demonstrate that EPA's existing approach to evaluating groundwater quality impacts from surface impoundments can be improved. This information will be useful in future API comments on EPA proposals regarding regulation of industrial nonhazardous waste facilities.

AN ASSESSMENT MODEL FOR VENTING GASOLINE-RANGE HYDROCARBONS IN SOILS

OBJECTIVE: To optimize the design and operation of soil venting systems for cleaning up gasoline-contaminated soils through the development of a simulation model.

STATUS: The contractor will develop a three-dimensional, multiphase, compositional transport model. The model will be designed to simulate hydrocarbon transport and microbial degradation under general venting scenarios, simulating the mass flow of air through the soil, the transfer of volatile hydrocarbons from the liquid phase to the vapor phase, and the biodegradation of less volatile hydrocarbons. (Enhanced biodegradation due to increased oxygen provided during venting is a likely synergistic effect of venting but has not been quantified.) Of particular importance will be the modeling of these processes at the capillary fringe where high-moisture conditions complicate both modeling and hydrocarbon removal. A preprocessor will be developed to facilitate site-specific input required by the transport model. The transport model will be verified through comparison with field data from a USGS field research site. A method to optimize venting system design (i.e., number, location, and pumping rates for venting wells) will also be developed. Work has been initiated on the characterization of the field site and adaptation of the USGS MODFLOW model to airflow modeling. Decision variables and cost information are being collected for the venting optimization model. Field experiments were conducted over the summer and fall months to validate the venting flow and transport model, including effects on biodegradation. A draft final report and model software are expected in December

1991. The model will enable member company personnel and others to assess the feasibility of soil venting for remediation of gasoline-contaminated soils, optimize venting well sites, and simulate performance of the soil venting system.

EXPOSURE/RISK ASSESSMENT FRAMEWORK FOR THE MANAGEMENT OF SUBSURFACE CONTAMINANTS

OBJECTIVE: To develop a computerized, decision-based framework to assess site- specific target or clean-up levels and corresponding exposure potentials, thereby facilitating decision-making in establishing clean-up requirements.

STATUS: A software system is to be developed to provide chemical fate/transport, exposure, and environmental impact/risk analysis of sites at which petroleum hydrocarbon releases have occurred. Based on user inputs, the software system is to estimate exposure levels and potential risks/environmental impacts corresponding to user-specific site- and chemical-specific target or clean-up levels. The software system is to specify statistical confidence intervals on the derived exposure levels and assess the significance of the exposure levels in relation to existing environmental and human health criteria/standards.

An initial 1991 amendment ($45K) provides for upgrading the unsaturated zone fate and transport model, SESOIL, which is to be revised and retrofitted into the exposure/risk assessment software. Revisions will include enhancements of the model's mass balance capabilities and simplification of model input requirements. SESOIL documentation will also be improved and updated.

An additional 1991 amendment ($40K) provides for 1) development of a site characterization module to allow more detailed input of site-specific data, 2) incorporation of a state-of-the-art model for estimation of air emissions, and 3) enhancement of the software system's user interaction and data presentation capabilities. Draft sections of the user's manual have been reviewed, and the contractor is incorporating comments. A preliminary version of the exposure/risk assessment software system and a revised user's manual are due in late December 1991.

The final user's manual and software are due by March 1, 1992, incorporating comments from beta testing of the draft software system. The software will assist member companies in quantitatively evaluating potential exposures and risks associated with gasoline releases to groundwater and in proposing to state agencies technically sound cleanup standards to minimize these exposures/risks.

PETROLEUM RELEASE DECISION FRAMEWORK

OBJECTIVE: To develop a framework that facilitates cleanup decision-making at contaminated spill sites (soil and groundwater) based on an assessment of exposure and site considerations.

STATUS: The contractor has developed a three-component, computerized decision framework for evaluating the contamination potential of a subsurface release with respect to any down-gradient receptor. The framework offers assistance to the user in rapidly accessing information on key variables needed for input into decision making. These variables include hydrogeologic characteristics, chemical toxicity, persistence, transport, pathways, etc. The framework focuses on the importance of exposure consideration in deriving site-specific cleanup requirements. The end product is a user- interactive software package based on the promulgated UST Final Rule on subsurface releases, as covered under various sections dealing with emergency response, health and safety requirements, site assessment, characterization, and cleanup. Because of the flexibility inherent in the program, one can access data from a built-in database (information from API Publication No. 1628) and call in other stand-alone programs to perform additional tasks or calculations (there are several saturate and unsaturate models under development in other groundwater-related projects). The Petroleum Release Decision Framework (PRDF) User's Manual (API Publication No. 4528) and software are available for distribution. The PRDF will provide users with information on the decision-making process involved in site characterization and remediation. The framework will be especially useful in conducting negotiations with regulators at state and local levels on what, when, and how to carry out release management activities.

DETECTION / ANALYTICAL METHODS

SAMPLING AND ANALYSIS OF SOILS FOR GASOLINE RANGE ORGANICS

OBJECTIVE: To identify and test appropriate sampling and analysis methods suitable for determining low levels of gasoline constituents in the soil.

STATUS: Using results from a literature survey on specific sampling and analytical methods, a workshop of experts identified promising approaches worthy of further investigation. In the laboratory, the performance of several sampling and analytical methods for BTEX and total hydrocarbons was evaluated using several soil types spiked with an artificial gasoline mix. Finally, both fresh and weathered gasoline samples were obtained from the field and analyzed in the laboratory to confirm real-world applicability of these methods. A new method has been developed and approved for distribution. Comments on the final report are being incorporated by the contractor. The method incorporates field methanol extraction in a VOA vial that can be directly analyzed by purge-and-trap GC/PID (i.e., without further manipulation of the field sample). Total petroleum hydrocarbons can also be determined by coupling a FID in series with the PID.

The purge-and-trap method has a lower detection limit (<100 ppb), but its dynamic range is limited on the high end (i.e., it is too sensitive to handle soils with the higher levels of contamination commonly found in field situations). A screening technique may be necessary as a first step. Work on an additional method to analyze distillate-range organics in soil is being initiated with the EPA Office of Underground Storage Tanks. The final report is being prepared for publication.

EVALUATION OF SUPERCRITICAL FLUID EXTRACTION (SFE) FOR ANALYSIS OF PETROLEUM INDUSTRY WASTES

OBJECTIVE: To determine the applicability and limitations of SFE in the routine analysis of a wide spectrum of industry waste types, and to assess the performance and utility of currently available methods and equipment.

STATUS: The types of aqueous and solid samples to be evaluated will be selected with priority given to those matrices that currently provide the greatest extraction/analytical problems (e.g., soils, sludges). Aqueous matrices are less likely to be good SFE candidates, but an effort will also be made to evaluate one or more types of water samples (e.g., effluent). CO2 will be the primary extraction solvent evaluated, but modifications will also be considered. Samples will be extracted by standard methods, and the recovery efficiency and reproducibility compared to that of SFE. Sample size, method detection limits, volume of waste solvent produced, time for sample extraction and analysis, estimated costs, and potential field applications will be compared with those of current standard methods. The general "degree of difficulty" of reliably performing the extractions/analyses will also be characterized. Research results will be used to provide guidance regarding the usefulness of SFE for different matrices and analytical methods. They will help in the development of new analytical methods and will provide technical support for anticipated API comments on new EPA methods.

6.0

R, D, & D NEEDS AND PRIORITIES FOR THE DESRT PROGRAM

by

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ABSTRACT

As part of an attempt to clean up contaminated sites in Canada, the Canadian Council of Ministers of the Environment (CCME) established the National Contaminated Sites Program. One of its components is DESRT, the Development and Demonstration of Site Remediation Technology. In order to focus this development program, a statement of Canadian research, development, and demonstration (R, D & D) needs and priorities was required by DESRT administrators. This statement was to provide the technical framework from which to review unsolicited proposals, and prepare requests for proposals for directed research.

The approach to this project consisted of two parallel activities. The first was aimed at defining the nature of the problems at contaminated sites in Canada. The second activity was aimed at summarizing the technologies and research needs applicable to site characterization, assessment and remediation. Following the completion of these activities, R, D & D needs which had the highest potential to solve the type of problems encountered in Canada and satisfied the objectives and priorities of the DESRT program were identified and prioritized.

R, D & D NEEDS AND PRIORITIES FOR THE DESRT PROGRAM

INTRODUCTION

As part of an attempt to clean up contaminated sites in Canada, the Canadian Council of Ministers of the Environment (CCME) established the National Contaminated Sites Program. One of its components is DESRT, the development and demonstration of contaminated site remediation technology. In order to focus this development program, a statement of Canadian research, development, and demonstration (R, D & D) needs and priorities was required by DESRT administrators. This statement was to provide the technical framework from which to review unsolicited proposals, and prepare requests for proposals for directed research.

The approach to this project consisted of two parallel activities. The first was aimed at defining the nature of the problems at contaminated sites in Canada. The second activity was aimed at summarizing the technologies and research needs applicable to site characterization, assessment and remediation. Following the completion of these activities, R, D & D needs which had the highest potential to solve the type of problems encountered in Canada and satisfied the objectives and priorities of the DESRT program were identified and prioritized.

The information used to complete this project was primarily secondary references including existing complications and evaluations of technologies and overviews of research needs developed by others (see attached bibliography), together with the experience and knowledge of the authors as derived through active participation in the field. The scope of the project precluded independent review of primary references for confirmation.

The nature and priority of contaminated sites in Canada were determined by augmenting the existing inventories of contaminated sites, which are variable in their approach and level of detail, with a survey of representatives from each province who had a working knowledge of the number and nature of the contaminated sites in their province. The results of this survey were augmented by the author's experience in the field to develop a "snapshot" of the nature of problems at Canadian sites.

The approach to site characterization, site assessment, and remediation technologies was to provide a concise overview of the technology with frequent referencing to source material and summary documents. Technology descriptions included consideration of advantages and disadvantages, application, uncertainties and needs for further research.

Efforts on evaluation of remediation technologies focused on 55 processes applying 10 technologies. The remediation technologies considered represented innovative technologies versus conventional technologies. Conventional remediation technologies were considered unlikely to provide significant opportunities for further R, D & D and were therefore eliminated from further consideration. The innovative remediation technologies retained for consideration in this project are listed in Table 6.1. The conventional remediation technologies considered but then eliminated are listed in Table 6.2.

R, D & D needs and priorities were developed by coupling the research needs for the technologies considered with the high priority problems at contaminated sites in Canada together with the objectives and priorities of the DESRT program

This paper provides a concise overview of the project which was commissioned by Environment Canada. A more exhaustive treatise is provided in the project report (CH2M HILL, 1992).

Table 6.1
Innovative Technologies Evaluated as Part of This Project

Biological Treatment Technologies

- In situ
- Aboveground
  - Landfarming
  - Bioreactors

Thermal Treatment Technologies

- Incineration
  - Rotary Kiln
  - Fluidized Bed/Circulating Combustion Chamber
  - Infrared
  - Heat Soaking Furnaces
  - Liquid Injection
  - Industrial Process
- Pyrolysis
- Vitrification
  - High Temperature Slagging
  - Plasma Reactor
  - Flame Reactor
  - Electric Reactor
  - Cyclone Combustor
  - In Situ Vitrification
- Molten Salt
- High Temperature/High Pressure Steam
- Low Temperature Technologies
  - Low Temperature Desorption
  - Oil Recovery - Taciuk Process
  - Valorization of Chlorinated Residues (VCR)
  - Mercury Roasting
- Radio Frequency Heating
- In Situ Steam Heating

Physical/Chemical Treatment Technologies

- Soil Washing
  - Pumping (groundwater extraction)
  - Water Washing
  - Surfactant Extraction
  - Acid/Base Extraction
  - Chelating Agents
- Solvent Extraction
  - Basic Extraction Sludge Treatment (BEST^R) Process
  - Extraksol^R Process
  - ENSR Solvent Extraction Process
  - Carver Greenfield Process
  - B.P. Oil Solvent Extraction Process
  - Accurex Solvent Extraction Process
  - Soilex Process
  - EETD Solvent Extraction Process
  - Hot Toluene Extraction
  - CF Systems Extraction
- Dechlorination
  - APEG Process
  - Eco Logic Process
  - Radiolytic Dechlorination
  - Electrochemical Dechlorination
- Oxidation Reactions
  - Chlorine Dioxide Soil Catalyzed Reactions
  - Soil Catalyzed Reactions
  - Ozone
- Solidification/Stabilization
  - Cement/Pozzolans
  - Lime
  - Organically Modified Clays
  - Thermoplasts
  - Macroencapsulation
  - Polymerization
  - Silicates
  - Ground Freezing
- Membrane Processes
- Photolysis
- Electroacoustics
- Soil Vacuum Extraction (SVE)
- SVE Enhanced Biodegradation
- In Situ Aeration

Table 6.2
Conventional Technologies Eliminated from Evaluation

Air Stripping	
Carbon Adsorption	
Precipitation	Hydroxide Sulfide Carbonate
Wet Air Oxidation	Conventional Processes Vertical Tube Reactor Supercritical Water

STATUS OF CONTAMINATED SITES IN CANADA

The nature of the problems at Canadian sites have not been inventoried in a consistent manner, if they have been characterized at all, and the problems at many sites in Canada are not well documented. In order to take some direction from the existing inventories of contaminated sites, it was necessary to also utilize some professional judgement.

The following synopsis of the high priority contaminated sites in Canada was prepared to guide future R, D & D work:

i) Sites contaminated with petroleum by-products including fuels, oils, and heavy distillates are now, and likely will continue to be, a source of site contamination in Canada due to the ongoing reliance on fossil fuels and the wide distribution and number of these products/facilities. Specific contaminant groups include aromatic hydrocarbons and polynuclear aromatic hydrocarbons. Media affected include solids (soil/sludge), water, soil gas, and the atmosphere (due to the volatility of the contaminants).

ii) Halogenated organic solvents are contaminants of concern due to their mobility in the environment, their toxicity, their wide distribution, and previous management practices. Media affected include soil, groundwater, and soil gas, and the atmosphere.

iii) Soil contaminated by metals occurs primarily at industrial and disposal sites and typically does not pose a problem until re-development is proposed. Shallow soil contamination typically requires remediation to mitigate phytotoxicity and dermal exposure concerns. Metals in aqueous form and metals associated with suspended particulates (in air and water) can be of concern at mine tailings sites. In particular, acid generating tailings are of concern, as metals may be more mobile under acidic conditions.

iv) Sites contaminated with PCBs and/or dioxins are typically a high priority for remediation, but these contamination problems are generally localized and of small scale (ie. limited areal extent and quantity).

v) It can be expected that contamination due to a variety of chemicals will be typical for site clean-up rather than contamination due to one or two compounds. This reflects the multitude of chemicals associated with the activities which cause site contamination (i.e. manufacturing, distillation, waste disposal, etc.).

vi) High priority sites are more commonly located close to population centres whereas remote sites are less likely to be of high priority due to the lower potential for adverse human health impacts and socio-political reasons.

vii) The scale of contaminated site problems consists of many small sites and a fewer number of intermediate and large sites. The historical practice of excavation of small and medium size contamination problems followed by landfilling is becoming uneconomical emphasizing the need for alternate approaches to manage all scales of site contamination problems.

viii) Identification and remediation of immiscible organics (halogenated and non-halogenated) or NAPL (non-aqueous phase liquids) represents a continued technical challenge at many sites.

SITE CHARACTERIZATION AND ASSESSMENT

SITE CHARACTERIZATION

There is an overwhelming need to develop and evaluate improved methods of site characterization which both provide necessary data and have lower utilization costs. Essentially all site characterization projects utilize some form of drilling investigation. These investigations are extremely costly and introduce considerable disturbance into the system being investigated. Furthermore, the intensity of sampling required to develop a high level of confidence in the site characterization is cost-prohibitive leading to significant uncertainty in the site characterization results. Significant benefits stand to be gained by developing alternative methods for intrusive as well as non-intrusive investigation methods. Potential technologies identified by DOE (1989) include:

- Fibre optics
- Novel drilling techniques
- Remote sensing
- Field data management systems
- Field instruments that incorporate computerized data processing and expert systems

The areas recommended where R, D & D efforts should be focused for improving site characterization are as follows:

- Improved or alternate intrusive (i.e. drilling) methods which create less disturbance, are quicker and less costly (i.e. vibratory methods).

- Methods to improve the reliability and cost-effectiveness of groundwater and soil characterization. Possibilities include:

    - alternatives to conventional monitoring well construction, development and sampling (i.e. Hydropunch)
    - development of more reliable indicator parameters (i.e. TOX) and cost-effective broad screening analysis (i.e. TPH, GC/MS open characterization)
    - utilization of biological monitoring (i.e. toxicity testing) instead of detailed chemical analysis to represent chemicals not analyzed or which do not have criteria and provide an indication of actual impacts

- Development of alternate or improved non-intrusive testing methods (i.e. geophysics), in particular those which:

    - can detect and map NAPL
    - can detect dissolved or residual organic contaminants
    - are effective beneath buildings and other infrastructures

- Development of methods to reliably detect and quantify NAPL in the subsurface.

- Development of methods to characterize heterogeneities which provide the necessary data to allow assessment and remediation.

- Development of reliable methods to quantify the total mass of contamination present in various phases and to monitor the change in distribution during remediation.

SITE ASSESSMENT

The priority areas for further research within the context of the DESRT program for site assessment, defined as the evaluation and interpretation of site characterization data, are as follows (Mangold and Tsang, 1991; DOE, 1989):

- Incorporation of biological reactions into contaminant transport models
- Development of models to reliably simulate contaminant transport in fractured media and the unsaturated zone
- Development of methods to characterize uncertainty in risk assessments
- Application of stochastic methods to the exposure assessment in risk assessments
- Improvements in the data linking human and particularly ecological exposures to actual uptake of chemicals in the environment
- Improvement in the toxicological evaluations for chemicals commonly encountered at potentially contaminated sites
- Understanding the significance of heterogeneities to site assessment
- Improved application of geostatistical methods to data management and presentation
- Coupling of data management and evaluation tools to enable more effective and extensive site assessment. Areas of greatest interest/potential include:
  - Geographical information systems (GIS)
  - Decision support systems (i.e. OASIS)

REMEDIATION TECHNOLOGIES

A short list of remediation technologies was developed for identification/prioritization of R, D & D needs based on the technologies considered in Table 6.1. The selection process used was judgemental in nature. The primary factors considered were the potential for broader application of lower cost technologies which are most applicable to the type of contaminated site problems found in Canada. The technologies included on the short list are as follows:

- Biological Technologies
  - In Situ Bioremediation
  - Aboveground
    - Landfarming
    - Slurry Bioreactors
- Thermal Technologies
  - Low Temperature Desorption
  - Taciuk Process
  - In Situ Steam Heating
  - Radio Frequency Heating
- Physical/Chemical Technologies
  - Soil Washing
    - Pumping (extraction)
    - Water Washing
    - Acid/Base
    - Chelating Agents

  - Surfactants
- In Situ Solvent Extraction
- Photolysis
- SVE
- In Situ Aeration
- Dechlorination
  - APEG
  - Eco Logic
  - Radiolytic
  - Electrochemical

In identifying R, D & D needs for each of these remediation technologies, ten research needs were identified which were common to most technologies. These common research needs are as follows:

- Define range of application
- Define removal efficiency/levels
- Contaminants addressed
- Cost
- Enhancements to scope of application
- Process control/monitoring
- Prediction/modelling
- Equipment design/development
- Pre-/Post-treatment
- Soil type/geologic considerations

In particular, the lack of good documentation on the individual contaminants or mixtures treated, the range of applicable physical site conditions (i.e. soil type), the removal efficiency and the ability to achieve cleanup goals were common issues for most technologies.

A number of research needs were also common between technologies applied either in situ or aboveground. Common research needs for in situ technologies included:

- Methods to overcome/enhance remediation in the presence of heterogeneities
- Methods to improve performance in fine-grained soils (i.e. clays)
- Remediation of the capillary fringe
- Definition of removal efficiencies and acceptable levels of residual contamination
- Understanding of process control (i.e. prevention of the spread of contamination, remobilization of NAPL)

Common research needs for aboveground technologies were:

- Methods to improve performance in fine-grained soil (i.e. clays)
- Identification and acceptability of residue management alternatives
- Definition of removal efficiencies
- Portability and permitting

The approach for prioritizing R, D & D needs was to rank the 10 common research needs (presented previously) relative to each other for each of the technologies considered. An 11th category covering technology-specific considerations (which are discussed later in this section for each technology) was also included. The results of this ranking process are summarized in Table 6.3.

R, D & D needs were categorized by the stage of development of the technology, as discussed below to the extent possible. Remediation technologies at the demonstration stage were given a high priority relative to basic research, consistent with the priorities of the DESRT program as outlined in Environment Canada (1991).

The stages of technology development that were used in categorizing R, D & D needs are as follows:

Table 6.3
Prioritization of Research Needs Common to All Short List Technologies

Research Needs	Biological			Thermal				Physical/Chemical												
		Aboveground						Soil Washing									Dechlorination			
	In Situ	Landfarming	Bioreactors	Thermal Desoprtion	Taciuk Process	R.F. Heating	In Situ Steam	Pumping	Water Washing	Surfactants	Acid/Base	Chelating Agents	Solvent Extraction (In Situ)	Photolysis	SVE	In Situ Aeration	APEG	Eco Logic	Radiolytic	Electro Chemical
1. Define Range of Application	1	3	3	1	1	2	2	3	1	1	1	2	1	1	2	2	1	3	1	1
2. Define Removal Efficiency/Levels	1	2	2	1	1	1	1	3	1	1	1	1	1	1	1		1	3	1	1
3. Contaminants Addressed	1	3	3	1	1	2	2	3	1	1	1	2	1	1	3	2	1	3	1	1
4. Cost	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3
5. Enhancement to Scope of Application	1	1	1	3	3	1	3	1	2	3	3	3	3	2	1	2	3	3	3	3
6. Process Control/ Monitoring	1	2	2	3	3	1	1	3	3	3	2	1	2	2	2	1	1	1	2	3
7. Prediction/Modelling	2	2	2	3	3	2	2	3	2	2	2	1	3	3	1	2	3	3	3	3
8. Equipment Design/ Development	3	3	3	3	3	3	3	3	3	2	3	3	3	1	3	1	3	3	2	2
9. Pre-/Post-Treatment	3	3	2	2	2	2	2	3	3	1	3	3	2	2	1	3	1	2	1	1
10. Soil Type/Geologic Considerations	1	2	2	2	2	2	2	1	2	1	1	1	2	3	1	2	1	1	2	1
11. Other	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

- **Basic Research.** The objective of the research phase is to identify and understand fundamental processes. It often takes 5 to 10 years or longer for the results of such research to be incorporated into commercial technology.
- **Development.** This phase is the bridge between basic research and field applications of a technology. It often requires a period of 2 to 5 years for the results obtained in the technology phase to be incorporated into commercial technology.

- **Demonstration.** This phase involves application of an innovative technology on a scale, and with a protocol, appropriate for demonstrating the feasibility, applicability, and effectiveness of the technology in full-scale, commercial applications. Results obtained in the demonstration phase can readily be incorporated into commercial technology.

The R, D & D needs were prioritized, with a rating of 1 indicating the highest priority and a rating of 3 indicating the lowest priority. High priority refers to the issue/uncertainty requiring the most attention to allow application of the technology. While a variety of sources were used on this project, the input given the most significance in this prioritization was the authors' project experience and perceptions of current R, D & D findings and trends. Some of the specific criteria used in the prioritization are briefly described below:

- **Period required for results to be incorporated into commercial technology.** R, D & D, topics having the potential for more timely incorporation into commercial technology, were generally given a higher priority. The USEPA has given a high priority to properly designed and documented field demonstrations. The rationale for prioritization of field demonstrations includes the following:

    - Findings can more readily be incorporated into commercial technology
    - The need for quantified application information on the cleanup level achievable (accounting for all removal mechanisms), duration, and cost
    - The need for broader access to design information
    - The need for peer-reviewable information that can be used to adjudicate contradictory information from vendors and consultants and to overcome user scepticism
    - A critical assessment of field applications will identify technology limitations that will be the basis of applied research

    Thus, most of the needs related to remediation technologies at the demonstration category were given a high priority.

- **Developments offering the most potential for broader applicability and lower cost.** For example, bioventing is viewed as having the potential for applicability to a wide range of contaminants and for overcoming the rate-limiting factor in current in situ bioremediation technology: supply of the required electron acceptor mass.

- **Findings of research conducted to date.** To the extent possible, results of ongoing research were considered. For example, R, D & D topics that are the focus of ongoing research that to date have yielded results not considered promising were given a lower priority.

The identification and prioritization of R, D & D needs is summarized in Table 6.3 and discussed briefly by technology in later sections of this paper.

To provide further guidance in matching the R, D & D needs to the groundwater and soil problem types in Canada, the pertinence of each technology was ranked for each of the 8 high priority problem types. That is, the pertinence of all the short list technologies were compared to each other and ranked from high pertinence (1) to low pertinence (3) for each of the high priority problem types. The basis for this evaluation was again judgemental and was based on the experience of the authors. The results of this evaluation are summarized in Table 6.4.

As a final step in the evaluation of remediation technologies, the technologies on the short list were ranked according to their pertinence to the Orphan sites identified as of the time of report preparation. A total of 10 sites were identified across the country that will receive funding under the Orphan program. A key consideration in the prioritization of R, D & D needs, based on direction received from Environment Canada, was that the technologies applicable to problems at Orphan sites were preferable. The pertinence of each technology was ranked from 1 to 3 with a 1 representing high pertinence as described previously. The results are presented in Table 6.5.

BIOLOGICAL TECHNOLOGIES

The level of interest and amount of research activity related to the application of biological technologies to soil and groundwater remediation has mushroomed in the last 3 to 5 years. The achievements thus far have only begun to tap the opportunities for bioremediation. EPA's March 1991 "Bioremediation in the Field" newsletter listed 140 projects where bioremediation was being considered, planned or implemented. Research projects too numerous to list in this paper, have been undertaken by several organizations. A number of publications/programs exist which summarize these research activities, and these documents should be consulted when reviewing proposals for bioremediation projects. These include:

- Biosystems Technology Development Program (EPA, 1990)
- "Bioremediation in the Field". Information update (EPA, 1991)
- Hazardous Substance Research Centers Program (EPA, 1990)
- Environmental Research Centers Program (EPA, 1991)

The general research needs for bioremediation include:

- Application and enhancement of bioremediation in cold weather environments
- Assessment of application to complex waste mixtures and structurally complex compounds
- Development of methods to adapt to different site conditions, such as soil type and waste form
- Identify additional microorganisms which degrade selected contaminants and understand the metabolic process by which they work
- Develop methods and procedures needed to enhance rate, extent and scale
- Develop experience in taking bioremediation technologies to the field
- Identification/isolation of enzymes that catalyze biodegradation
- Properly designed and documented field demonstrations

The general research needs for bioremediation are summarized in Table 6.6 according to stage and priority for further research.

Identification and ranking of specific research needs for in situ bioremediation and above ground bioremediation are summarized in Tables 6.7, 6.8, 6.9 and 6.10.

THERMAL TECHNOLOGIES

LOW TEMPERATURE DESORPTION

This technology is applicable to address soil contaminated with halogenated and non-halogenated volatile contaminants. This technology is potentially applicable in situations where other lower cost technologies (i.e. SVE) cannot be applied or are not cost-effective. For instance, stationary operations in centralized locations could be used to remediate small to medium size soil contamination problems,

Table 6.4
Ranking of the Potential of Each Short Listed Technology to Solve Canadian High Priority Problems

Potential to Solve Canadian High Priority Problems (from Chapter 2)	Biological			Thermal				Physical/Chemical												
		Aboveground						Soil Washing									Dechlorination			
	In Situ	Landfarming	Bioreactors	Thermal Desoprtion	Taciuk Process	R.F. Heating	In Situ Steam	Pumping	Water Washing	Surfactants	Acid/Base	Chelating Agents	Solvent Extraction (In Situ)	Photolysis	SVE	In Situ Aeration	APEG	Eco Logic	Radiolytic	Electro Chemical
Petroleum By-products	1	1	1	1	2	2	1	3	3	2	NA	3	2	3	1	1	NA	NA	NA	NA
Mine Tailings	NA	NA	NA	NA	NA	NA	NA	2	1	NA	1	1	NA	?	NA	NA	NA	NA	NA	NA
Miscellaneous Chemicals	3	3	2	3	3	3	3	2	1	2	2	2	3	3	3	3	3	3	3	3
Metal Contamination	NA	NA	NA	NA	NA	NA	NA	2	1	NA	1	1	NA	?	NA	NA	NA	NA	NA	NA
PCBs/Dioxins	3	3	3	3	2	2	2	3	2	2	NA	NA	2	?	3	3	1	1	1	1
PAHs/Coal Tar	3	2	1	3	2	3	2	3	2	1	NA	NA	2	3	3	3	NA	NA	NA	NA
Phenolic Hydrocarbons	1	1	1	3	2	3	3	2	2	3	NA	NA	3	?	3	2	NA	NA	NA	NA
Mixed Inorganic Waste	NA	NA	NA	NA	NA	NA	NA	2	1	NA	1	1	NA	NA	NA	NA	NA	NA	NA	NA

Table 6.5
Ranking of the Pertinence of Each Short Listed Technology to Orphan Site Problems

Pertinence to Problems Identified at Orphan Sites to Date	Biological			Thermal				Physical/Chemical												
	In Situ	Aboveground		Thermal Desoprtion	Taciuk Process	R.F. Heating	In Situ Steam	Soil Washing					Solvent Extraction (In Situ)	Photolysis	SVE	In Situ Aeration	Dechlorination			
		Landfarming	Bioreactors					Pumping	Water Washing	Surfactants	Acid/Base	Chelating Agents					APEG	Eco Logic	Radiolytic	Electro Chemical
Pacific Place, B.C.	2	2	1	3	2	3	2	3	1	1	1	1	1	?	2	2	NA	NA	NA	NA
Canada Creosote, Alta	3	2	1	3	2	3	2	3	1	1	NA	NA	1	3	3	3	NA	NA	NA	NA
Peerless Wood Preservers, Cayley, Alta	3	2	1	3	2	3	2	3	1	1	NA	NA	1	3	3	3	NA	NA	NA	NA
Purity 99, Hartell, Alta	1	1	1	1	2	2	1	3	3	2	NA	3	2	3	1	1	NA	NA	NA	NA
Hagersville, Ontario	3	2	1	3	2	3	2	3	2	1	NA	NA	1	3	3	3	NA	NA	NA	NA
Smithville, Ontario	3	3	3	3	3	2	1	3	3	1	NA	NA	1	3	3	3	2	2	2	2
Saint Jean-Sur-Richelieu, Que.	NA	NA	NA	NA	NA	NA	NA	3	1	NA	1	1	NA	NA	NA	NA	NA	NA	NA	NA
Saint Amable, Que.	3	2	1	3	2	3	2	3	2	1	NA	NA	1	3	3	3	NA	NA	NA	NA
Five Island Lake, N.S.	3	3	3	3	3	2	2	3	1	3	1	1	3	NA	NA	NA	1	1	1	1
Former Scrap Yard, Saint John, N.B.	3	2	1	3	3	3	3	2	1	2	2	2	3	3	3	3	3	3	3	3

Table 6.6
Identification and Prioritization of General Bioremediation R, D & D Needs

Basic Research	Technology Development	Technology Demonstration
(2) Standardized techniques for monitoring the "microbiology of bioremediation"	(2) Standardized techniques for monitoring "the microbiology of bioremediation" (e.g. viable biomass)	(1) Field demonstrations with appropriate protocols and controls to provide peer-reviewable, quantified data on: • Cleanup level achievable • Fate process mass balance • Duration • Cost • Effectiveness of enhancements (e.g. inoculation) • Influence of site-specific factors
(1) Survival, growth, and activity of exogenous microorganisms (e.g. commercially available microbial cultures)	(1) Standardized protocols for assessing bioremediation applicability (technology screening phase)	
(2) Increasing the bioavailability of soil-bound and/or organic-bound contaminants		
(3) Genetic engineering to increase the contaminant biodegradation metabolic capabilities of "Microbial Systems"		
(1) The identification, toxicity, and mobility of biodegradation intermediates and end products		
(1) Enhanced biodegradation of recalcitrant organics (e.g. 4- to 6-ring PAHs, PCBs) through addition of amendments that increase bioavailability and/or result in co-metabolism		
(3) Environmental risk analysis of introduction of genetically engineered microorganisms to the environment		
(2) Biodegradation of recalcitrant organics in waste mixtures containing readily biodegraded organics (e.g. RSKERL PCB work)		
(1) Investigate natural biodegradation processes that may lead to unique bioremediation applications (e.g. methantopic biodegradatoin of chlorinated solvents and related process, white rot fungus)		

Note: The parenthetical number appearing at the beginning of each need indicates the relative priority, with No. 1 being the highest and No. 3 being the lowest.

Table 6.7
Identification and Prioritization of In Situ Bioremediation R, D & D Needs

Basic Research	Technology Development	Technology Demonstration
(1) Microbial ecology and biogeochemistry of contaminated sites	(1) Standardized protocols for determining the microbial ecology and biogeochemistry of contaminated sites	(2) Remediation of BTEX contamination with nitrate as the terminal electron acceptor (Traverse City)[a]
(2) Inorganic nutrient demands, attenuation, and delivery	(3) Enhancements of methods for delivery of oxygen to the saturated zone	(1) Remediation of chlorinated solvents through stimulation of methanotrophic microbial activity (St. Josephs)[a]
(1) Contaminant biotransformation under anoxic conditions (necessary for evaluating contaminant attenuation under natural conditions and for assessing potential use of alternate electron acceptors)	(3) Methods to enhance methanotrophic biodegradation of chlorinated solvents in the vadose zone	(1) Bioventing (emphasis on cleanup level achievable)
(2) Microbially enhanced contaminant leaching (biosurfactant production) to reduce the subsurface oxygen demand	(1) Protocols for design of bioventing systems (gas flow, optimal nutrient and moisture conditions, etc.)	(2) Remediation of fuel hydrocarbons with hydrogen peroxide biostimulation (Traverse City)[a]
	(2) Methods for coupling anaerobic, reductive dehalogenation with aerobic, methanotrophic biodegradation of chlorinated solvents	(1) Aerobic bioremediation of fuel (BTEX) contamination
	(1) Coupling of in situ bioremediation with in situ soil flushing technologies (hot water or surfactant flooding) to increase practicality of in situ bioremediation through reducing subsurface oxygen demand	
	(2) Tools for more accurately modeling in situ bioremediation (for predictive and evaluation purposes)	

[a] Indicates a "non-Canadian" state-of-the-art project already underway or planned.

Note: The parenthetical number appearing at the beginning of each need indicates the relative priority, with No. 1 being the highest and No. 3 being the lowest.

Table 6.8
Identification and Prioritization of General Bioremediation R, D & D Needs

Basic Research	Technology Development	Technology Demonstration
(3) Contaminant biodegradation capabilities of white rot fungi	(3) Methods for seeding/maintaining/optimizing activity of white rot fungi	(1) Mass balance considering all removal mechanisms/fate processes
	(2) "Solid phase bioreactors" (e.g. rotating cylinder) for soil treatment	(1) Comparative demonstration (e.g. temperature effects) of conventional land treatment versus composting (aerated soil pile)
	(1) Addition of amendments (e.g. surfactants or general organics") to increase the desorption and bioavailability of bound contaminants	
	(2) Optimization of tilling depth and frequency versus duration (land treatment)	

[a] Indicates a "non-Canadian" state-of-the-art project already underway or planned.

Note: The parenthetical number appearing at the beginning of each need indicates the relative priority, with No. 1 being the highest and No. 3 being the lowest.

Table 6.9
Identification and Prioritization of Slurry Bioremediation R, D & D Needs

Basic Research	Technology Development	Technology Demonstration
(2) The survival, growth, stability, and activity of bacterial inoculum (probably most feasible for reactors versus in situ or solid phase)	(1) Addition of soil amendments (e.g. surfactants or general organics[a]) to increase desorption and bioavailability of bound contaminants	(1) Field demonstration with focus on integrated treatment train, including soil washing for removal/treatment of coarse fraction and dewatering of fines
	(2) Design tools (models)	
	(3) Methods for increasing biomass loading and sludge age	
	(3) Use of growth subtrate when low concentration of organic contaminant is rate limiting	

[a] Indicates a "non-Canadian" state-of-the-art project already underway or planned.

Note: The parenthetical number appearing at the beginning of each need indicates the relative priority, with No. 1 being the highest and No. 3 being the lowest.

Table 6.10
Identification and Prioritization of Other Bioremediation R, D & D Needs

Basic Research	Technology Development	Technology Demonstration
(2) The survival, growth, stability, and activity of inoculum (probably most feasible for reactors versus in situ or solid phase)	(2) Bioreactor design based on minimization of volatile emissions (e.g. anoxic reactors, packed bed bioreactors)	(2) Comparative evaluation of bioreactor configurations
	(3) Use of growth subtrate when low concentration of organic contaminant is rate limiting	
	(2) Design tools (e.g., sizing, media selection) for biofilters for treatment of gaseous waste streams	(1) Biofilters for treatment of gaseous waste streams (e.g., stripper offgas)
	(2) Reactor design for biodegradation of chlorinated solvents	

[a] Indicates a "non-Canadian" state-of-the-art project already underway or planned.

Note: The parenthetical number appearing at the beginning of each need indicates the relative priority, with No. 1 being the highest and No. 3 being the lowest.

such as fuel spills/leaks. Portable applications could be used for all problem scales, such as if time constraints existed for remediation or in situ processes were not feasible.

Technology-specific issues requiring further information include:

- Better definition of the applicability to various mixtures (i.e. fuel types) and specific contaminants. For instance, by defining the range of vapour pressures to which the technology applies.
- Documentation of the treatment efficiency for various applications (i.e. percentage removed, soil type).
- When is pretreatment required (i.e. clay soils).

Potential research needs identified other than the 10 common needs were as follows:

- Overcoming restrictions to equipment portability and permitting of mobile equipment.
- Identification of acceptable management options for condensate and treated soil.

TACIUK PROCESS

The Taciuk process could potentially be applied to soils containing recalcitrant organics which cannot be addressed by more economical methods (i.e. bioremediation). Potential applications could include residual oils from spills, residual NAPL contamination on soil, or coal tar/creosote/PAHs.

Research issues include:

- Applicability to and success with non-oils and identification of governing factors (i.e. vapour pressure)
- Need for post-treatment and applicable technologies/enhancements to achieve acceptable cleanup levels
- Applicability to soil types other than sands

Research needs other than the most common areas were:

- Identification of acceptable management options for recovered fluids and treated soil
- Portability of equipment

RADIO FREQUENCY HEATING

Radio frequency heating has potential to remediate semi-volatile organic contamination, located in the unsaturated zone. A significant number of issues exist which need to be addressed with further research, in particular, the potentially high cost of application due to high energy needs. Outstanding research needs include:

- Application at depth
- Application below the water table
- Application to fine-grained soil
- Defining the range of contaminants to whch it applies and associated cleanup levels (and cost)
- Enhancements by combination with SVE
- Ability to control contaminant migration during treatment (i.e. prevent lateral movement, re-mobilize NAPL to greater depths)
- Importance and control of a steam sweep
- Post-treatment requirements to achieve acceptable cleanup levels
- Application to fine-grained and heterogeneous soil

IN SITU STEAM HEATING

In situ steam heating is considered to have application in a narrow set of circumstances where the severity of contamination warrants cleanup of immobile organic contaminants which cannot be addressed by less costly methods. Research needs include:

- Developing a better understanding of the effects of soil moisture and condensation during treatment
- Performance/application/enhancement in fine-grained and heterogeneous soils
- Process control (i.e. re-mobilization and collection of NAPL, recovery of contaminants)
- Definition of the range of contaminants/mixtures to which technology is applicable and efficient
- Application to the capillary fringe

PHYSICAL/CHEMICAL TECHNOLOGIES

SOIL WASHING

Pumping (Groundwater Extraction)

The research needs for this application of soil washing deals primarily with methods to enhance treatment efficiency in areas where the technology is marginal. The enhancements are considered as different applications of in situ soil washing (i.e. the use of surfactant addition, acid/base and chelating agents) or different technologies (i.e. in situ bioremediation, bioventing, in situ aeration) and are discussed separately. The main research needs for pumping focus on improving the understanding of the processes involved and on monitoring, as follows:

- Investigation of improvements to efficiency through pulse pumping
- Basic research in fate and transport processes
- Developing better capabilities to:

  i) predict remediation results
  ii) determine when pumping alone is feasible and when its not

This includes better understanding of geochemical processes, affect of heterogeneities and performance in the presence of NAPL.

Water Washing

Water washing, defined as aboveground soil washing, is the sole application of soil washing and the only technology which can address a wide variety of organic and inorganic contaminants in soil. It has high potential application to the cleanup of many industrial/commercial sites where numerous contaminants exist that cannot be addressed by other technologies (or where several technologies would be required). The technology is proven and has been applied elsewhere. Research needs include:

- Better availability of basic process and process train information
- Enhancements to address fine-grained soil
- Methods to reduce sludge volume
- Increase effectiveness of treatment
- Definition of management options for residues and their acceptability (i.e. post-treatment requirements)

Surfactant Extraction

Surfactant extraction holds significant potential to remediate moderate and highly immobile organic contaminants in relatively permeable soils. Research needs are as follows:

- Documentation on environmentally acceptable surfactants, their range of application, contaminants addressed and efficiency
- Improvements in delivery systems
- Post-treatment requirements for surfactant recovery or destruction
- Understanding of the fate of surfactants in the environment
- Applicability to/enhancement of treatment in fine-grained soil and heterogeneous environments
- Deficiency of full-scale demonstration exists

Acid/Base Extraction

In situ application of acid/base extraction is considered in this section. Aboveground applications are covered under Water Washing and enhancements to that application. In situ use of acid/base extraction could be used to treat metal contamination, if subsurface conditions are amenable to in situ processes.

Research needs at the development and demonstration stage include:

- Process control to prevent release of acidic or basic process water or spread of contamination (i.e. overcome concerns of adverse environmental impacts)
- Process control to achieve effective cleanup while minimizing acid/base consumption
- Investigate claims regarding possible application of base extraction to various organics (i.e. volatiles, mineral oils, PAHs, chlorinated hydrocarbons)
- Reduction in sludge volume

Chelating Agents

The use of chelating agents is effectively an enhancement to in situ or aboveground soil washing with water. Research needs are at the technology development stage and include:

- Assessing application of various chelants to different contaminants
- Understanding and minimizing competing ion effects/interactions
- Applicability to different soil types

IN SITU SOLVENT EXTRACTION

In situ solvent extraction has limited application due to the fact that many solvents are in themselves contaminants. The challenge with in situ solvent extraction is to identify solvents which are both effective in remediation and acceptable from an environmental perspective yet cost-effective. Alcohol-based solvents (i.e. methanol, ethanol, propanol) have some potential application in this area.

PHOTOLYSIS

Photolysis is directed at recalcitrant organic compounds including PCBs, dioxins and furans. Research needs are at the bench scale stage and include:

- Basic research on reaction rates and mechanisms.
- Limitations to depth of pentetration.
- Information on factors that affect the effectiveness of photolysis
- Characteristics of breakdown products

SOIL VACUUM EXTRACTION (SVE) AND SVE ENHANCED BIODEGRADATION

Providing that free product or dissolved product exists in the subsurface, those compounds which have sufficiently high vapour pressures and a high Henry's Law Constant are most amenable to SVE. Research requirements and/or demonstration projects, which are applicable to the topic of SVE, relate mainly to mass transfer limitations inherent in the soil properties, chemical properties, and site conditions. The research requirements tabulated below are from CH2M HILL (1990).

Soil Properties

- Define typical diffusion rates (water or air) associated with organics trapped in fine grained geologic materials
- Although some success has been documented for hydrocarbon removal by SVE operations in fractured rock, a lack of effective monitoring schemes exist. A detailed study in a fractured rock environment is needed.
- The role of porosity needs to be evaluated, especially as it relates to fine grained materials.
- The role of sorption/desorption has significant implications on the treatment time for SVE. The influence of moisture content and adsorption/desorption rates requires further evaluation.

Contaminants Removed

- The role and behaviour of multi-component mixtures requires further study, especially as they relate to vapour pressures, solubility, and Henry's Gas Law Constant.
- The fate of higher chained residual contamination from gasoline contamination requires evaluation.
- The documentation of improved performance of heated reinjected soil gases emerging from catalytic oxidation. Could higher boiling point compounds be volatilized?

Site Conditions

- Heterogeneities cause operational problems for SVE. Could extraction/injection wells be placed in strategic locations to maximize the effective removal of the organic contaminants and, if so, how can well locations be determined.
- Fundamental research work is still required on the process affecting contaminant migration through the capillary fringe. Hoag (1989) has suggested some mechanisms, however this area of study still requires fundamental research.
- Cleanup schemes in the capillary fringe require more evaluation. Schemes such as water table lowering and air injection into the water table need to be evaluated. Comprehensive test results for capillary zone remediation do not appear to be widely published.
- The prediction of cleanup times requires further work.

IN SITU AERATION

The basic principal of in situ aeration involves the injection of air above or below the water table for the purpose of volatilizing organic compounds. Soil properties, chemical properties, and site conditions which limit the mass transfer of organic contaminants to subsurface air stream in the SVE process, are similar to the in situ aeration process. As such, research needs pertaining to mass transfer problems with the SVE, are similar in the aeration process. However, since the in situ aeration process may also be applied in the saturated zone, including the capillary fringe, additional research needs are created. Additional needs include:

- What are typical zones of influence which may be expected from an air injection well?
- What effect does a pulsating airflow have on operating performance?

- How efficient is the mass transfer rate in the vadose zone under the influence of in situ aeration?
- What air emissions are encountered with such a process?
- modelling of biological activity under the influence of in situ aeration.

DECHLORINATION

Dechlorination is applicable to chlorinated organics such as PCB dioxins. Research needs are at the development and demonstration stage. The main research needs focus on improving removals in clay-rich or organic-rich soils. Further research is also required to determine potential for broader application.

APPROACH TO REMEDIATION TECHNOLOGY ASSESSMENT

The present approach adopted, at least in North America, is to develop technologies from the laboratory testing to the field demonstration stage. The current thinking appears to be that well documented, peer reviewable demonstration projects are required to reduce the uncertainties and possible biases in previous demonstrations. The need for rigorously conducted field demonstrations is not questioned, only the focus. Demonstrations are needed to understand the range of applicability to different contaminants and mixes, the performance in different geologic environments/soil types, and the treatment efficiency. It is recognized that it is not practical to investigate all combinations and permutations in the field. The purpose of demonstrations should be to define the range of conditions or niche under which the technology is applicable and the constraints on taking the technology to the field.

Treatability testing will always be required to address the specific problems at any one site. Demonstrations should serve to provide sufficient data to screen technologies to the point where the few most applicable technologies can be compared through further testing.

Together with the need for demonstrations, a need also exists to conduct comparative evaluations of potentially applicable technologies under consistent and well controlled environments. A centralized facility equipped to conduct a wide variety of bench- and pilot-scale studies is advocated as an approach to cost-effectively evaluate and compare technologies with respect to treatment efficiency, rate and residual contamination levels. Such a facility could provide contract research services to the public and private sector on an as needed basis.

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U.S. EPA'S BIOREMEDIATION FIELD INITIATIVE: PERFORMANCE EVALUATION STUDIES AT A MONTANA SUPERFUND SITE

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ABSTRACT

The U.S. Environmental Protection Agency (EPA) has instituted a Bioremediation Field Initiative (BFI) to evaluate performance of bioremediation processes at sites employing field applications of such technologies. The Initiative is designed to generate a better understanding of bioremediation field applications in terms of treatment effectiveness, operational reliability and cost. One of the BFI sites selected Is the Champion International Superfund Site, Libby, Montana (Libby Site). The EPA's Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma (RSKERL), is directing performance evaluation activities at the Libby Site. This paper provides an introduction to the BFI and discusses design and operational plans for the 3 types of bioremediation technologies being used in the Libby Site remediation effort, performance evaluation study plans for each technology, and technology performance data generated to date. Although the research in this article has been funded wholly or in part by the U.S. EPA through Contract No. 68-C8-0058 to Dynamac Corporation, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

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BIOREMEDIATION FIELD INITIATIVE

The term bioremediation encompasses a suite of biological treatment technologies which are thought to be viable for treating a wide variety of organic hazardous wastes. Generally, such technologies have not been fully utilized nor evaluated, especially at field scale, for the many different types of waste sites at which remediation is required. The BFI was established by the EPA as a cooperative effort between the Agency's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) to provide EPA, other federal, and state remediation decision-makers; consulting engineers; and industry with timely information regarding new developments in application of bioremediation technologies at hazardous waste sites. The BFI provides for evaluation of performance at selected pilot and/or full-scale field applications; technical assistance to regional EPA Remedial Project Managers (RPMs) and On-Scene Coordinators (OSCs) through ORD Technology Support Centers (TSCs); and development of a biotreatability data base through the Alternative Treatment Technologies Information Center (ATTIC).

To date, the following 7 sites have been selected for field evaluation of bioremediation performance under the BFI:

1. Allied Signal Superfund Site, St. Joseph, Michigan (chlorinated solvents) - treatment of contaminated ground water using an in situ bioremediation system;
2. Park City Pipeline Spill, Park City, Kansas (petroleum hydrocarbons) - treatment of contaminated ground water using an in situ ground water bioremediation system;
3. Hill Air Force Base, Utah (petroleum hydrocarbons) - treatment of contaminated soils using a bioventing system;
4. Eielson Air Force Base, Alaska (petroleum hydrocarbons) - treatment of contaminated soils using a bioventing system;
5. Brookhaven Superfund Site, Brookhaven, Mississippi (wood treating chemicals) - treatment of contaminated soil from waste sludge piles using white rot fungi;
6. Public Service and Electric Facility, Denver, Colorado (Petroleum hydrocarbons) - treatment of contaminated ground water using an in situ bioremediation system; and,

7. Champion International Superfund Site, Libby, Montana (wood preserving chemicals) - treatment of contaminated ground water using a combined pump and treat fixed-film bioreactor and in situ bioremediation system, and treatment of contaminated soil in a prepared bed land treatment unit (LTU);

LIBBY SITE PERFORMANCE EVALUATION PROJECT

Superfund activities ongoing at the Libby Site, a former wood treating facility which used creosote and pentachlorophenol (PCP) as wood preservatives, involve remediation of contaminated soils and ground water. At the request of the Region 8 RPM, scientists from the RSKERL Superfund TSC have been providing technical support pertaining to remedial activities at the Libby Site since 1987. The BFI performance evaluation project, implemented in 1991, is under direction of these TSC scientists.

Performance Evaluation Background

The BFI has 3 primary objectives: 1) document performance of bioremediation field applications in terms of treatment effectiveness, operational reliability, and cost; 2) provide technical assistance to EPA and State RPMs responsible for overseeing or considering use of bioremediation as a remedial alternative; and (3) develop a biotreatability data base. The Libby Site project is designed to address performance of bioremediation field applications only in terms of treatment effectiveness and operational reliability.

The potentially responsible party (PRP), Champion International, is cooperating with the RSKERL in carrying out the proposed project. The RSKERL is providing technical direction and oversight for planning, data interpretation and reporting of results from performance evaluation studies being conducted for each bioremediation process in operation at the Libby Site. These studies are being conducted by a team of engineers and scientists from Utah State University (USU).

The Libby Site uses 3 types of biological treatment processes in the site remediation scenario (Figure 1): (1) oil-water separation of extracted ground water, followed by aqueous phase treatment in a fixed-film bioreactor; (2) in situ bioremediation of the upper aquifer; and, (3) soil biological treatment in a prepared-bed, LTU.

The projected date for reporting final results from surface bioreactor and LTU performance evaluation studies is December, 1992; the performance evaluation report for the Upper Aquifer in situ bioremediation evaluation is due in December, 1993.

This paper presents a summary of design and performance information and monitoring data available prior to the field study phase of the Libby Site performance evaluation project, as well as performance data for samples collected during 1991. The paper is based on information extracted by the USU staff from reports provided by the PRP, Woodward-Clyde Consultants (PRP site remediation contractor), and Region 8 RPM; plus data generated from analysis of samples collected at the site during 1991.

Performance Evaluation Project Phases

The Libby Site bioremediation performance evaluation project consists of 2 phases. Phase I, completed in May, 1991, addressed each Site treatment process with regard to design, operational and monitoring activities. Specific tasks in phase I involved: 1) summarizing site bioremediation activities; 2) identifying site characterization and treatment parameters required to evaluate performance for each type of biological treatment unit; and, 3) formulating design plans for field activities required to fully assess performance of each treatment unit. This information is contained in an internal EPA report detailing Phase I activities which was prepared by the RSKERL in August, 1991 and submitted to OSWER's Technology Innovation Office .

Phase II is designed to implement perforation evaluation activities identified in Phase I of the project. A primary objective of Phase II involves statistical evaluation of polycyclic aromatic hydrocarbons (PAHs) and PCP degradation in ground water, aquifer materials and soil. This includes intergradation and coordination of activities and evaluation of data for each type of site bioremediation technology. Proposed Phase II activities pertaining to each bioremediation technology are presented in subsequent sections of this paper.

LIBBY SITE BIOREMEDIATION TECHNOLOGIES

Upper Aquifer

The Upper Aquifer has been contaminated by disposal and spills of creosote and PCP from past wood treating operations. The plume of contaminated ground water extends to more than 1 mile in length. Although both Upper and Lower Aquifers are contaminated, current remedial activities are focused on the Upper Aquifer due to concerns over potential risks posed by the plume and potential for contaminating additional off-site wells.

The EPA Record of Decision (ROD) called for final Upper Aquifer cleanup levels of 40 parts per trillion (ppt) for total carcinogenic PAHs; 400 ppt for total noncarcinogenic PAH; 1.05 mg/liter for PCP; 5 ug/liter for Benzene; 50 mg/liter for Arsenic; and a human health threat no greater than 10^{-5} for concentrations of other organic and/or inorganic compounds.

Fixed Film Bioreactor Treatment System

The surface bioreactor treatment system provides for separation of light and dense non-aqueous phase liquids (LNAPLs and DNAPLs) from ground water extracted downgradient from the waste pit source area, followed by biological treatment for PAH and PCP removal. Treated effluent is reinjected upgradient of the waste pit area and serves as part of the overall Upper Aquifer in situ bioremediation program. The system is designed to accomplish approximately 90% PAH removal from pumped ground water having an average influent concentration of 7,000 µg/L PAH. An estimated 21% collateral PCP removal also is expected, based on results of the system demonstration study.

The aqueous-phase biological treatment system (Figure 2) involves two major design components: 1) oil/water separation, and 2) fixed-film bioreactor treatment.

Oil/Water Separation Process

Considerable amounts of oil may be extracted with ground water. In an effort to reduce organic loading on the bioreactor and to allow for possible recycling of oil, oil/water separation is provided prior to biological treatment.

Two ground water extraction wells located downgradient from the periphery of the waste pit currently are used to extract ground water for bioreactor treatment. Although designed primarily to remove LNAPL, sufficient storage is available for DNAPL removal, if required. Separated oil accumulates in a tank from which it is removed for recycling or disposal.

The oil/water separator has the following design components:

- separator dimensions (cylindrical tank)
  diameter = 8 ft (2.43 m)
  length = 29 ft (8.84 m)
- inlet and outlet piping = 3 in (7.5 cm)
- flow rate = 40 gpm (220 m^3/day) maximum
- total active volume = 10,000 gal (38 m^3)

- hydraulic detention time = 16.6 h at 10 gpm
- separator temperature = ambient (50°F or 10°C anticipated)

Bioreactor Treatment Process

The bioreactor treatment unit is used to treat aqueous effluent from the oil/water separator. Two fixed-film bioreactors with plastic packing material are operated in series in an up-flow mode. Influent temperature is controlled, and nutrient levels are supplemented by addition of ammonium chloride and potassium tripolyphosphate.

Pertinent design features of a bioreactor system for the Libby Site were investigated by Woodward Clyde Consultants. The system consists of the following design components:

- bioreactor dimensions;
  diameter = 11 ft (3.35 m),
  height = 14 ft (4.27 m)
- flow rate = average, 40 gpm (220 m^3/day) maximum
- total active volume = 20,000 gal (38 m^3)
- hydraulic detention time = 30 hr (based on empty bed volume)
- reactor temperature = 30°C
- dissolved oxygen (DO) = > 2 mg/L
- Ph = 6.5 - 7.5

System controls include:

- ground water flow rate and source
- air flow/oxygen source
- temperature
- nutrient addition (NH_4Cl, $K(H_2PO_4)_3$)
- contaminant loading rates (PAH, PCP)

Reactor 1 in the treatment series is for roughing purposes; reactor 2 is for effluent polishing and reoxygenation prior to reinjection. Separator effluent is pressure filtered to remove any remaining NAPL, and nutrients are added, prior to entry to the first reactor. Flow enters each reactor via a manifold system at the bottom and is withdrawn through perforated effluent pipe above the packing medium. Effluent from the second reactor passes through a strainer before entering the reinjection dosing tank. Reactor heating is by internal heating coils filled with glycol heat transfer fluid, supplemented by external heat exchangers. Air is sparged into each reactor through 4 porous spargers, and is supplemented by in-line spargers.

Process Monitoring

Operational monitoring of the ground water extraction system consists of checking flow rates and pumping pressures, and routine inspection of the well system. The separator unit is monitored by visual inspection of separator tank NAPL level.

Operational monitoring of bioreactors consists of continuous or daily monitoring of: DO; temperature; Ph; and water, nutrient amendment and air flow. Aqueous grab samples are collected weekly for PAH, PCP, and oil and grease analysis. Nutrient amendment system monitoring consists of routinely recharging the system with nutrient batch, conducting a tank inspection, and calibrating the metering pump. Routine checks on operation of aeration and heating systems also are conducted.

Fixed-film Bioreactor Performance Evaluation

Planned BFI bioreactor performance activities include:

- Flow composite sampling of influent, intermediate, and effluent flows;
- Analysis of PAHs, PCP and other selected parameters to evaluate and predict reactor performance;
- Analysis of biofilm dynamics (thickness, PAHs)
- Parallel operation of bench scale system to evaluate effect of operational changes for optimization
- Mass balance of contaminants in the bioreactor
- Treatment optimization evaluation with respect to in-situ processes

Phase II activities are planned for completion during the spring and summer of 1992. Evaluation of data from system design and PRP operational reports plus data from preliminary samples collected by USU indicate that the oil/water separator currently is not performing properly, and that bioreactor performance deteriorates when influent flow rate exceeds the minimum design flow rate (10 mgd). Bioreactor performance evaluation activities cannot be fully implemented until operational problems are corrected. The PRP is working to correct the identified operations problems.

In Situ Bioremediation

The in situ bioremediation program objective is to achieve, to the fullest extent practical, removal of PCP and PAH compounds from ground water at the Site. A combination of biological treatment technologies are proposed for this purpose, including: 1) extraction of contaminated ground water, treatment in a fixed-film bioreactor, and reinjection upgradient of the waste pile area; and 2) in situ bioremediation of the Upper Aquifer. Feasibility and potential effectiveness of in situ bioremediation in degrading PCP and PAH contaminants to established clean-up levels were previously investigated at this site in a pilot study conducted by Woodward Clyde Consultants between 1987 and 1988.

In Situ Pilot Study

A pilot in situ bioremediation system, installed in 1987, utilized 2 well clusters located within the contaminant plume for injection of hydrogen peroxide and nutrients. Existing monitoring wells were employed for system monitoring.

At each well cluster location, a 100 mg/liter hydrogen peroxide solution was injected into 2 zones within the upper aquifer to stimulate aerobic biodegradation of PCP and PAHs. Pilot study results indicated that injection of this solution created a zone of elevated DO within the plume. Ground water samples collected from within this zone indicated lower concentrations of total hydrocarbon contaminants compared to the untreated region. Reduction in PAH and PCP concentrations were attributed to the combined presence of microbial populations, DO and nutrients.

Based on pilot study results, a demonstration program for in situ remediation was designed and implemented to gain additional data on system performance. The program, beginning in 1990 and still ongoing, was designed to generate additional data as the basis for the final bioremediation strategy.

In Situ Demonstration Program

System components for the in situ demonstration program consist of: 1) ground water extraction system immediately downgradient of waste pit area, 2) sequential oil/water separator/bioreactor system to treat extracted ground water, 3) infiltration trench upgradient of waste pit source area to reinject treated and nutrient amended ground water; 4) injection system downgradient of pump and treat extraction wells for injection of hydrogen peroxide and nutrient solution intermediate into the contaminant plume; and 5) monitoring system to evaluate effects of demonstration program on oxic conditions and dissolved contaminant concentrations.

The approach taken involves addition of hydrogen peroxide as a source for DO, and inorganic nutrients to stimulate growth of indigenous microbial populations. The injection rate was designed to maintain approximately 100 mg/l hydrogen peroxide. Potassium tripolyphosphate and ammonium chloride are continuously added to maintain injection water nutrient concentrations of 27 mg/l and 22 mg/l, respectively.

The estimated area of increased DO levels due to hydrogen peroxide addition is 400 feet wide and 1000 feet downgradient from injection wells. Within this area, it is highly probable that distribution of DO is heterogeneous. The area of influence is being further evaluated during the demonstration.

Information regarding effects of injection of hydrogen peroxide and nutrients on reductions in plume contaminants are being obtained by monitoring dissolved concentrations of PCP and PAHs in samples from monitoring wells located in the vicinity and downgradient from injection wells.

Operational guidelines for the demonstration program in situ system consist of monthly measurements of DO and water depth in injection wells; periodic backwashing of sand filters; periodic recharging of hydrogen peroxide and nutrient tanks; and routine visual inspections. Peroxide and nutrient addition tanks require recharge approximately every 2 months and every 2 weeks respectively, based on continuous operation. The analytical sampling program for each monitoring well consists of monthly monitoring for DO, water level and temperature, and quarterly monitoring for PCP and PAHs.

Prior to initial injection of nutrients and peroxide, downgradient monitoring wells were sampled for PAH, PCP, DO and nutrient concentrations to establish baseline conditions. Baseline data and operational data from the demonstration program will be analyzed to estimate effects of in situ bioremediation on contaminated ground water. These data, in conjunction with aquifer properties determined from bromide injection tests, will be used to develop final design for the Libby Site in situ bioremediation program.

To date, demonstration program DO concentrations have been variable, but generally show modest increases in a number of downgradient wells. Increased DO concentration downgradient from injection wells seems to be vertically distributed reasonably well within the Upper Aquifer. Poor hydraulic connection between some injection and sampling wells may explain modest DO increases observed in several wells. Also, presence of significant amounts of oily substances in some wells may have resulted in insignificant changes in DO.

Groundwater samples are collected from 8 monitoring wells. Analysis of monitoring well samples collected to date have revealed the presence of carcinogenic PAHs. Five wells have shown decreased concentrations of total noncarcinogenic PAHs and PCP; 3 wells have shown increased concentrations. Average decreases between 2 sampling periods for total noncarcinogenic PAHs and PCP in all 8 monitoring wells have been reported as approximately 10% and 18%, respectively. These demonstration data indicate that enhanced biodegradation of dissolved contaminants in ground water may be occurring.

In Situ Bioremediation Performance Evaluation

The primary purpose of planned field activities for the in situ bioremediation performance evaluation is to assess the general magnitude of biodegradation. It is important to note that distribution of contaminants in the subsurface is highly variable due to heterogeneities of soil and aquifer material as well as heterogeneity of contaminant transport. Delineating contaminant distribution in the subsurface is beyond the scope of this project. However, bioremediation indicators, i.e., DO profiles, oxygen uptake, and contaminant concentration changes, will be used to qualitatively assess a profile for rate and extent of subsurface biodegradation. Quantitative expressions will be developed when data is sufficient. Laboratory studies will be conducted, and correlations with field studies will be drawn.

Specific BFI activities planned include:

- Determination of DO profiles
- Aquifer core material sampling to distinguish between abiotic and biotic effects
- Laboratory study to evaluate effects of sorption and biotransformation
- DO uptake evaluation/correlation to degradation rate
- Toxicity reduction as a function of degradation

Field activities associated with performance evaluations of the in situ system will be initiated in the spring of 1992 and continue into the summer of 1993. Some hydrogeological tests have been conducted to date to obtain better delineation of ground water flow patterns at the site prior to initiating extensive subsurface sampling activities. Push-pull tests have been unsuccessful.

Contaminated Soil

Contaminated soils from 3 primary source areas (tank farm, butt dip and waste pit) have been excavated, physically screened and placed in the waste pit area for pretreatment prior to placement in the LTU. Soil contaminants of concern include: 1) PAHs; 2) PCP; and, 3) dioxins.

Contaminated soils were screened to remove rocks larger than 1 inch in diameter. Removed rocks were placed just upgradient of the waste pit area for treatment using a percolation system. Screened soils were retained in the waste pit area for bioremediation using a 2-step, enhanced biodegradation treatment process. Step 1 (pretreatment) is used to reduce initial contaminant levels for subsequent treatment in a 1-acre LTU cell (Figure 3). Originally, this step involved stimulation of biodegradation within the waste pit area using a mixture of microbes, nutrients and other energy sources. Addition of microbes and other energy sources was discontinued at an early date. Step 2 involves placement and management of pretreated soils in the LTU, which also will serve as the final disposal location.

Total estimated contaminated soil volume for treatment is 45,000 cubic yards (uncompacted). Waste pit area soils are comprised of: 0-3% clay; 10-41% silt; 31-55% sand; and, 0.95-5.38% organic carbon. Initial soil contaminant concentrations, expressed as the geometric mean, are approximately 189 mg/kg total carcinogenic PAHs; 29 mg/kg PCP; and 0.9×10^{-3} mg/kg 2,3,7,8-TCDD equivalency.

Contaminated soil clean-up goals (dry-weight basis) are: 1) 88 mg/kg total (sum of 10) carcinogenic PAHs; 2) 8 mg/Kg naphthalene; 3) 8 mg/kg phenanthrene; 4) 7.3 mg/kg pyrene; 5) 37 mg/kg PCP; and 6) $\leq$ 0.001 mg/kg dioxin equivalency.

Prepared-Bed Land Treatment Unit (LTU)

The LTU is comprised of 2 adjacent 1-acre cells. Each cell is lined with low permeability materials to minimize leachate infiltration from the unit. When reduction of contaminant concentrations in all lifts placed in the LTU have reached acceptable levels, a protective cover will be installed over the total 2-acre unit and maintained in such a way as to minimize surface infiltration, erosion, and direct contact.

Contaminated soil is applied to and treated in lifts (approximately 9-inches in thickness) in the designated LTU cell until target soil contaminant levels are achieved for a given lift. Degradation rates, volume of soil to be treated, initial contaminant concentration, yearly degradation period duration, and LTU cell size determine time required for remediation of a given lift. Based on an estimated 45-day time frame for remediation of each applied lift to acceptable contaminant levels, an estimated 45,000 cubic yards of contaminated soil, and a 2-acre total LTU surface area, projected time to complete of soil remediation is 8-10 years.

Facility Design

Design criteria for each LTU cell include total containment of contaminated soils, water, and leachate, with ultimate treatment and disposal of all contaminated soils within the treatment unit.

Design components include:

- 2-acre surface area treatment unit (2, 1-acre cells)
- 30 inch depth treatment zone (12 inches silty material supported by 18 inches of sand)
- liner system (60 ml HDPE, compacted clay, geotextile filter fabric, geonet)
- leachate collection system (perforated pvc piping/gravel drains/sumps)
- rainfall runoff/leachate storage unit (two 50,000-gallon tanks)

Each LTU cell is surrounded by a berm consisting of low permeability, compacted soils and designed to control runon/runoff associated with a 25-year, 24-hour storm event. Each LTU cell is sloped 2% to a central gravel drain to accomplish water control within the unit. The gravel drain is sloped 1% to a gravel sump.

The treatment zone consists of 18 inches of sandy material supporting 12 inches of silty material. A composite liner system composed of a synthetic liner placed on top of soil compacted to a low permeability minimizes migration of leachate which might otherwise continue downward through unsaturated zone soils into ground water.

The leachate collection system is designed to collect leachate generated from 2 sources of water: (1) water applied during LTU operation, and (2) water from precipitation events. Surface water entering the site and ponding on the surface is pumped to two 50,000 gallon storage tanks for subsequent reapplication to the LTU, treatment in the bioreactor unit or other disposal option.

Process Monitoring

The LTU monitoring program involves periodic collection and analyses of leachate, soil, ground water, and air samples both outside and within the treatment cells during both the operation and closure periods. Post-closure care will include monitoring and inspection conducted for the unit following placement of a cap at the end of the closure period.

Monitoring in the vicinity of the LTU includes ground water and air sample collection systems. Background samples have been collected and analyzed to establish a baseline for evaluating data collected during LTU operation. The ground water monitoring system includes 6 wells (4 downgradient and 2 upgradient).

Monitoring within the LTU include soil, leachate, and air sample collection systems. Routine soil monitoring involves collection and compositing of samples from the uppermost lift of contaminated soil for on-site analysis. After target contaminant remediation levels have been obtained, samples are sent to an off-site laboratory for confirmation analyses. At the end of each treatment year, additional composite samples from each lift placed in the unit during that year are collected and analyzed. If target contaminant levels are not met by the end of a given year for composite samples of all lifts placed in a LTU cell in that year, LTU operations will be continued into the spring of the next year; and no additional lift placement in that LTU cell will be made until target levels are met.

Leachate monitoring involves collection of samples from LTU sumps on a quarterly basis and whenever leachate is produced during rainfall events. If concentrations of contaminants in the leachate are below EPA detection limits for a period of one year, leachate monitoring will be reduced to a frequency of twice annually.

Periodic air sampling is conducted to confirm that tilling operations do not cause migration of contaminants via the air pathway.

Closure

Closure of the LTU will commence following completion of standard treatment operations in both cells, i. e., all contaminated soils have been applied and target contaminant levels have been met. Closure activities will be designed to provide long term containment of disposed materials and protection of the environment. The LTU will be closed in a manner that: 1) minimizes need for further maintenance, and 2) controls, minimizes and eliminates, to the extent necessary to prevent threats to human health and the environment, post-closure escape of hazardous waste, hazardous waste constituents, leachate, contaminated runoff, or waste decomposition products to ground water, surface waters, or to the atmosphere. The closed facility will be monitored in a manner that will allow detection of any contaminant releases.

Criteria which will be used to initiate closure activities include: (1) little or no evidence of movement of organics beneath the treatment zone; (2) achievement of soil clean-up levels for all constituents; and (3) no detection of regulated contaminants in leachate samples for at least the last two years of operation of the facility. A regular program of tillage, watering, and maintenance of the land treatment area will be conducted until the above criteria are met.

The PRP has proposed that, if closure criterion No. 3 is met at the end of the LTU operational period, the following closure actions be taken: (1) redesign cover system to exclude the flexible geomembrane liner and drainage net, and (2) puncture HDPE liner at the bottom of LTU cells in the sump areas to allow leachate to gravity drain, thus avoiding any "bathtub" water accumulation in the system.

Ground water monitoring will be continued through the closure period. Two upgradient and 3 downgradient wells will be sampled semi-annually for target constituents.

The LTU cover system will consist of random fill placed over the treated soil. A 12-inch thick compacted soil liner will be placed above the random fill. A 30 mil HDPE geomembrane liner will be placed over the soil liner, and a 12-inch thick layer of cover sand will be added to protect the geomembrane. A 12-inch thick layer of topsoil will be placed above the cover sand, and used to establish a vegetative cover.

Final grading of the facility will maintain berms surrounding the LTU at a sufficient height to control runon, runoff, and wind dispersal. The berm will be raised with uncontaminated fill to contain the 25-year, 24-hour storm event.

Post-Closure Care

Primary activities during the post-closure period will include facility inspection and maintenance. Inspections of vegetative cover, runon/runoff control system, and LTU sumps will be performed monthly or after any major storm. The vegetative cover will be designed to adapt to the site climate; therefore, after the first year, irrigation will be discontinued. Facility access will be restricted by the Company security system and fencing around the site.

Post-closure care may be terminated after 5 years, if target constituents in soils, ground water, and leachate are not detected above selected remediation levels. The post-closure care period may be extended to 30 years if significant concentrations of target constituents are detected.

LTU Field Performance Evaluation

Phase II LTU performance evaluation activities include:

- Statistical sampling of LTU soil - periodic samples collected at multiple depths from 32 locations;
- Determination of treatment kinetics at field scale;
- Determination of toxicity reduction as a function of degradation;
- Correlation of microbial activity to kinetics;
- Evaluation of clean-up levels achieved at full-scale;
- Determination of intermediates formed from degradation of PAHs and PCP;
- Determination of rate/extent of humification of PAHs and PCP;
- Evaluation of moisture impacts on soil structure at field scale; and
- Determination of mass balance of soil contaminants using analytical data from LTU soil leachate samples.

Data quality objectives of the BFI performance evaluation program differ from objectives of the routine LTU monitoring program currently being implemented by the PRP at the Libby Site. Therefore, this project is not a parallel program to the existing site monitoring program. Instead, this project offers the opportunity to collect, compile, assimilate and interpret additional data and information not normally obtained during routine site bioremediation activities, due to either time, resource, or budgetary constraints.

The primary purpose of the LTU soil sampling program being carried out in this project is to determine statistical significance and confidence of rate and extent of contaminated soil biodegradation at this site. A quantitative expression for data variability is necessary to determine an accurate estimate of biodegradation of these contaminants at field scale. Such an expression will allow data generated to be used by others to help estimate biodegradation potential of similar type wastes under similar conditions at other sites. A critical element in design of this project involves obtaining a good representation of mass balance for those compounds being monitored. Correspondingly, assessment of degradation intermediates; humification; and leachate, soils, and air quality is planned. If Phase II sampling and analytical program design will allow tracking of target contaminants through the system, investigators can determine an accurate fate and transport profile which denotes biodegradation performance. Completion of other project activities such as degradation kinetics and toxicity reduction studies will generate data which can be used to help assess overall bioremediation effectiveness and, subsequently, to help predict performance of bioremediation processes at other similar sites.

Three field sampling events directed toward Phase II performance evaluation studies were completed during 1991. The first event,implemented during early May, consisted of collecting soil core samples for analyses immediately following placement of treatment lift #3 (first 1991 lift; lifts #1 and #2 were applied in 1990) in LTU cell #1. A second sampling event in late June involved collection of 32 soil core samples during treatment process for lift #3. In late July, treatment lift #4 (second 1991 lift) was placed in LTU cell #1 and lift #1 was placed in cell #2. A third sampling event in late September involved collection of 32 core samples from both LTU cell #1 and LTU cell #2. All 32 core samples collected for each sampling event penetrate to the bottom of treatment lift #1.

Performance Evaluation Data - Year 1

Data presently available from the three 1991 LTU sampling events are presented in Tables 1 - 8. Table 1 gives the chronology of lift applications and sampling events. Full results from these sampling events will be available after data quality checks are completed for the remaining data.

These data indicate that the variability inherent in lift application and sampling is high enough to account for any differences between discrete sampling regimes as in the performance evaluation, and composite sampling regimes as in the operations monitoring.

It may be noted in Table 2 that the pentachlorophenol concentrations have a lower variability in Lifts 1 and 2 than in Lift 3, applied just before sampling. Lifts 1 and 2 had been tilled many times since application, and perhaps this tilling had effectively mixed the soil sufficiently to reduce the spacial heterogeneity of the PCP concentrations. No doubt some of the lower variability is due to the lower concentrations of PCP in Lifts 1 and 2 at the sampling date being considered. If it is assumed that the initial concentrations of PCP at application were similar for all lifts, then there is some indication that the PCP concentrations are being reduced.

Phenanthrene concentrations (Tables 3 and 4) are lower than treatment levels except for a small number of the discrete samples. One high value in lift one (151 mg/kg) markedly increases the variability of the data in this lift. Otherwise phenanthrene levels were low even immediately after application of the lift (Lift 3).

Pyrene concentrations in the LTU are somewhat more variable than pentachlorophenol and phenanthrene concentrations. This may be partly due to the tendency of the larger molecule to be more strongly adsorbed on the soil, causing the measured concentrations to be more sensitive to variations in the efficiency of the extraction step in the analytical process. The concentrations in Lifts 1 and 2 are clustered near the treatment level, with many just above or just below the treatment level. The reduction in concentration is apparently good, especially in lifts 1 and 3. Since Lift 2 concentrations were low at application of the lift, the reduction is not as apparent as in Lifts 1 and 3.

The variability of the Total Carcinogenic PAHs concentration, being the sum of the variability of ten individual components, is high. The data variability precludes any definitive conclusion concerning concentration reductions for this parameter. Most of the concentrations are around the 88 mg/kg treatment level.

When the full suite of data is available for publication, preliminary conclusions concerning the effectiveness of bioremediation in this scenario during the summer of 1991 can be developed. At the present time, only tentative remarks can be offered. First, the apparent lack of complete congruence between ordinary monitoring data using composite sampling techniques and this performance evaluation data developed using exhaustive discrete sampling techniques is easy to rationalize. If the concentration values from the performance evaluation were taken as a universe of samples, and a subset of samples drawn from this universe and composited before analysis, the monitoring data could be readily replicated. The inherent variability of the chemical concentrations, the nearness of the concentration values to the treatment levels, and the monitoring sampling and compositing methods combine to cause unavoidable variations in data produced. Although perhaps different methodologies might serve to narrow the range of variation, probably there is an inherent uncertainty in determining soil concentrations that cannot be resolved, and regulatory decisions about attainment of treatment levels should take this into account.

Secondly, remediation of the waste compounds appears to be taking place, although lack of long term data precludes definitive conclusions at this time. Pentachlorophenol concentrations from lifts in place for some time previous to sampling are low, within the treatment level range. Phenanthrene levels appear to be near the treatment level range even at application. Pyrene levels, high before treatment, appear to have been markedly reduced during the 1991 treatment season. Total carcinogenic PAH concentration measurements are too variable to make any statement about remediation of these compounds as a group at this time.

These preliminary results from this performance evaluation indicate that wood treating waste contaminated soils are susceptible to remediation by biological means. The performance evaluation will be continued, with more sampling to take place during the summer of 1992. The two years of data should be sufficient to allow reasonably detailed conclusions about the applicability of bioremediation to wood treating waste contaminated soils under the conditions prevailing at the Libby site.

ACKNOWLEDGEMENT

Acknowledgement and thanks are extended to Dr. Ron Drake, Dynamac Corporation on-site contract manager for RSKERL's Superfund Technology Support Center Technical Support Contract, and Dr. Ron Sims, Utah State University subcontract project manager, for their efforts in ensuring that Libby Site performance evaluation studies provide appropriate bioremediation design, operational and performance information in an efficient and timely manner. Special thanks go to all involved Dynamac and USU staff for their diligent efforts in assembling, extracting, collecting, and evaluating site information and analytical data. A special acknowledgement is extended to Champlin International and Woodward Clyde Consultants for their cooperation in providing design, operational and monitoring information regarding bioremediation processes in operation at the Libby Site.

BIOGRAPHICAL INFORMATION

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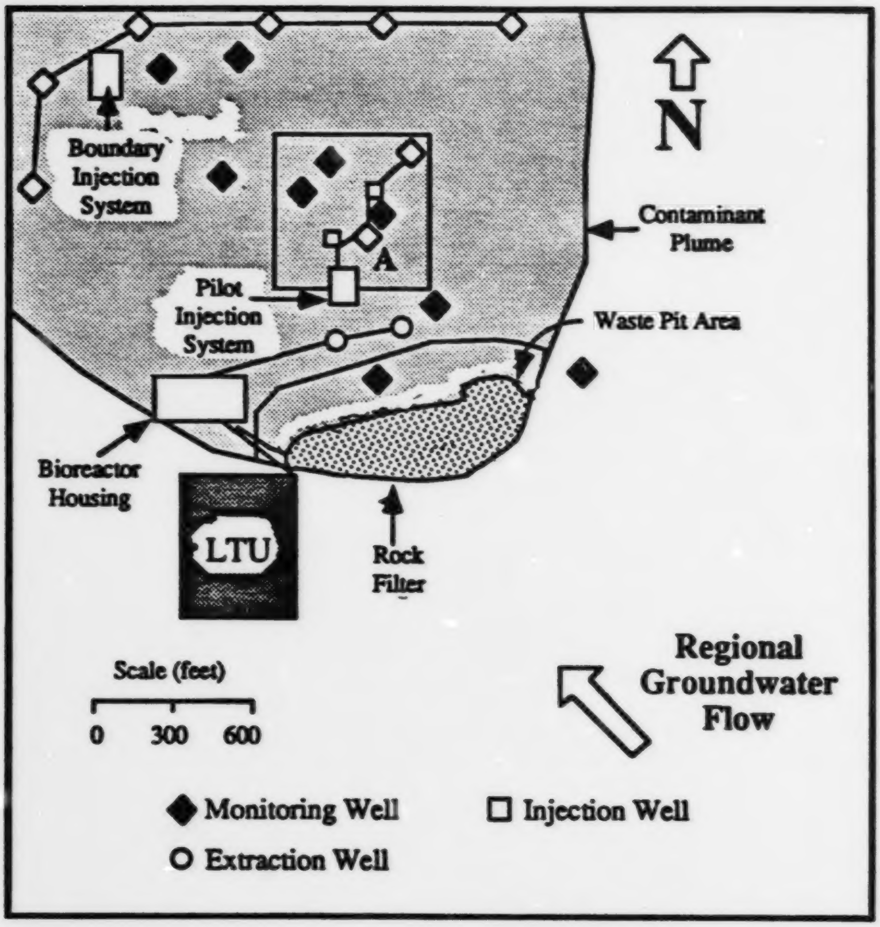
N
Boundary Injection System
A
Contaminant Plume
Pilot Injection System
Waste Pit Area
Bioreactor Housing
LTU
Rock Filter
Regional Groundwater Flow
Scale (feet)
0
300
600
◆ Monitoring Well
☐ Injection Well
○ Extraction Well

Figure 1. In Situ Bioremediation of Upper Aquifer (from Woodward Clyde)

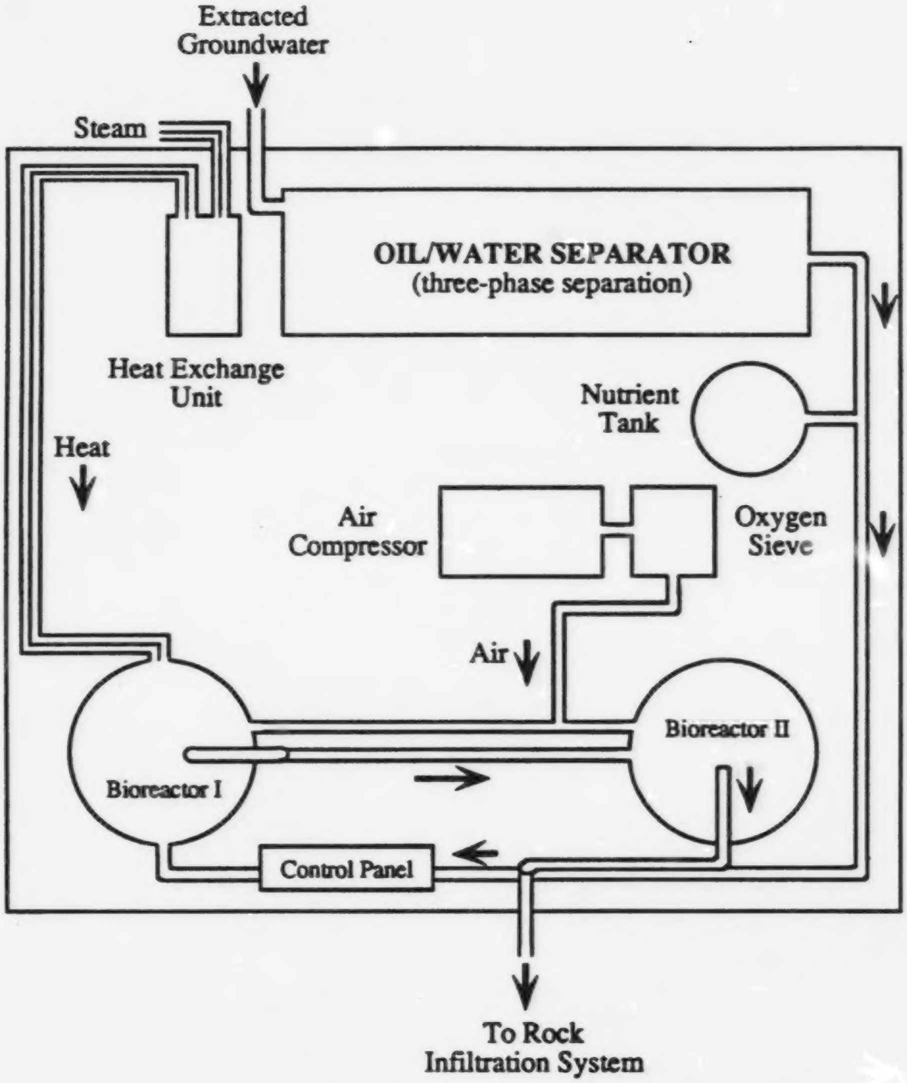
Extracted Groundwater
Steam
OIL/WATER SEPARATOR (three-phase separation)
Heat Exchange Unit
Nutrient Tank
Heat
Air Compressor
Oxygen Sieve
Air
Bioreactor II
Bioreactor I
Control Panel
To Rock Infiltration System

Figure 2. Ground Water Above Grade Treatment (after Woodward-Clyde)

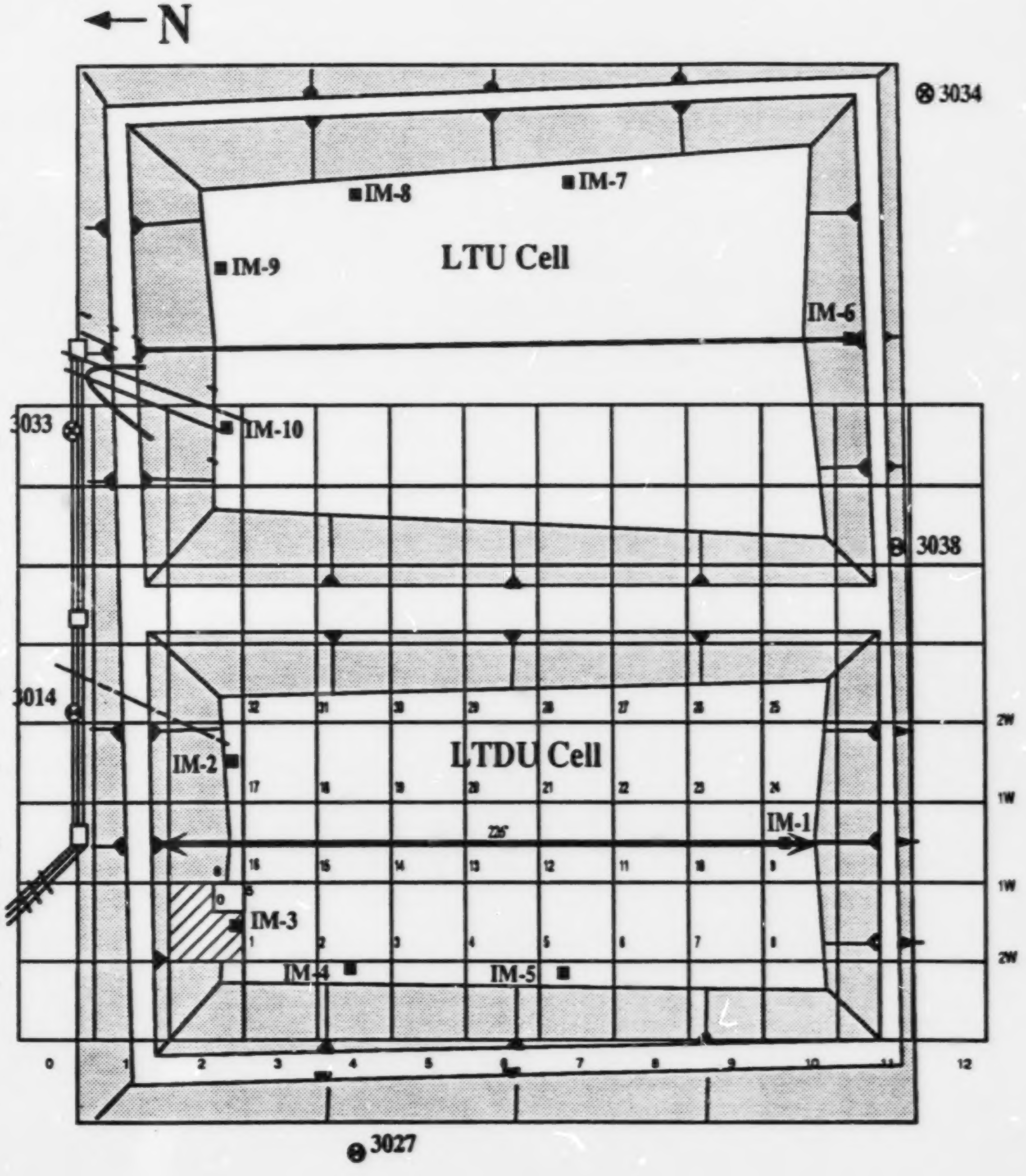
N
3034
IM-8
IM-7
LTU Cell
IM-9
IM-6
3033
IM-10
3038
3014
LTDU Cell
IM-2
IM-1
226'
IM-3
IM-4
IM-5
3027
2W
1W
1W
2W
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 3. The LTU with the grid showing reference point "R", and sample locations (after Woodward-Clyde)

Table 1. Chronology For Soil Sampling And Application Of Soil Lifts To The Libby LTU

Soil Sampling Event	Lift Application		
May 6 1991	Lift 1	Applied 6/21/90	
	Lift 2	Applied 8/8/90	
May 8 1991	Lift 3	Applied 5/8/91	
June 6 1991	Lift 1	Applied 6/21/90	
	Lift 2	Applied 8/8/90	
	Lift 3	Applied 5/8/91	
September 9 1991	Lift 1	Applied 6/21/90	
	Lift 2	Applied 8/8/90	
	Lift 3	Applied 5/8/91	
	Lift 4	Applied 7/27/91	

Table 2. Pentachlorophenol Concentrations In The Libby Soil Treatment Facility (mg/kg)

Sampling Date 5/6/91

Sampling Location		Feet South							
Feet East	Sample Depth	0	28.3	56.6	84.9	113.2	141.5	169.8	198.1
84.9	Lift 3	229	313	500	49	0	43	435	169
	Lift 2	30	155	33	12	12	144	79	9
	Lift 1	76	9	29	33	30	147	19	7
56.6	Lift 3	257	217	42	167	303	325	761	275
	Lift 2	4	15	21	0	0	58	40	15
	Lift 1	31	28	38	17	29	380	94	9
28.3	Lift 3	189	321	367	204	440	336	1243	1121
	Lift 2	0	9	21	17	11	11	35	2
	Lift 1	42	17	35	28	64	27	34	52
0	Lift 3	275	891	798	710	212	55	667	663
	Lift 2	226	26	177	18	24	12.5	67	29
	Lift 1	156	13	165	176	136	24	18	56

Table 3. Phenanthrene In The Libby Soil Treatment Facility (mg/kg)

Sampling Date 5/6/91

Sampling Location		Feet South							
Feet East	**Sample Depth**	0	28.3	56.6	84.9	113.2	141.5	169.8	198.1
84.9		**32**	**31**	**30**	**29**	**28**	**27**	**26**	**25**
	Lift 4								
	Lift 3								
	Lift 2								
	Lift 1								
56.6		**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
	Lift 4								
	Lift 3		8.2	3.2	3.7	0.3	5.0	9.4	12.8
	Lift 2	9.6		2.5	1.3	4.8	2.6	1.1	1.1
	Lift 1	5.2		ND	5.5	3.4	5.0	2.8	1.2
28.3		**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**
	Lift 4								
	Lift 3	14.4	ND	6.6	ND	10.1	5.7	2.0	2.8
	Lift 2	3.2	3.6	3.7	2.3	1.8	4.5	1.4	1.3
	Lift 1	151.0	4.5	0.1	3.4	16.7	4.4	1.6	2.4
0		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Lift 4								
	Lift 3	0.6	0.2	2.1	ND	6.2	7.2	1.7	0.7
	Lift 2	3.5	5.4	1.9	ND	2.6	3.3	2.5	2.4
	Lift 1	6.4	0.9	1.9	0.1	1.0	ND	3.5	7.8

Table 4. Phenanthrene In The Libby Soil Treatment Facility (mg/kg)

Sampling Date 9/18/91

Sampling Location		Feet South							
Feet East	Sample Depth	0	28.3	56.6	84.9	113.2	141.5	169.8	198.1
84.9		**32**	**31**	**30**	**29**	**28**	**27**	**26**	**25**
	Lift 4	5.6	6.6	6.4	4.4	7.4		7.5	10.9
	Lift 3	1.7	2.6	0.9	1.4	2.0	ND	4.0	3.1
	Lift 2	0.2	4.1	1.0	3.6	0.6	ND	2.7	7.0
	Lift 1	0.3	1.9	ND	0.8	0.6	ND	3.8	ND
56.6		**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
	Lift 4	3.1	5.6	6.3	7.2	10.2	8.7	10.5	4.5
	Lift 3	2.8	4.3	0.9	3.9	2.8	6.8	2.8	7.0
	Lift 2	1.6	1.6	2.7	8.1	4.7	2.1	1.2	4.8
	Lift 1	1.2	2.6	1.0	3.0	0.2	1.6	4.2	1.6
28.3		**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**
	Lift 4	12.0	4.8	3.8	2.4	4.9	3.3	ND	4.3
	Lift 3	3.3	0.8	3.7	ND	ND	3.0	ND	2.5
	Lift 2	13.0	1.6	ND	ND		1.7	ND	1.1
	Lift 1	2.7	1.4	3.5	3.1	2.8	3.7	1.4	1.9
0		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Lift 4	1.4	3.0	2.8	ND	ND	2.7	4.7	4.0
	Lift 3	0.2	0.9	2.9	ND	ND	0.8	2.3	ND
	Lift 2	6.1	2.9	4.6	0.2	2.0	ND	2.2	ND
	Lift 1	ND	2.5	3.3	5.5	3.6	3.5	3.5	1.6

Table 5. Pyrene In The Libby Soil Treatment Facility (mg/kg)

Sampling Date 5/6/91

Sampling Location		Feet South							
Feet East	Sample Depth	0	28.3	56.6	84.9	113.2	141.5	169.8	198.1
84.9		32	31	30	29	28	27	26	25
	Lift 4								
	Lift 3								
	Lift 2								
	Lift 1								
56.6		17	18	19	20	21	22	23	24
	Lift 4								
	Lift 3								
	Lift 2								
	Lift 1								
28.3		16	15	14	13	12	11	10	9
	Lift 4								
	Lift 3	79.4	159.6	75.9	92.7	118.0	82.0	105.3	110.0
	Lift 2	ND	23.7	17.1	13.4	10.1	7.9	ND	10.8
	Lift 1	266.6	26.4	3.8	14.4	ND	18.8	ND	9.1
0		1	2	3	4	5	6	7	8
	Lift 4								
	Lift 3	8.9	62.7	95.9	66.1	39.6	80.1	28.4	44.9
	Lift 2	11.3	13.3	15.4	ND	19.8	ND	17.2	6.1
	Lift 1	23.3	3.3	8.1	28.2	14.3	133.6	30.7	ND

Table 6. Pyrene In The Libby Soil Treatment Facility (mg/kg)

Sampling Date 9/18/91

Sampling Location		Feet South							
Feet East	Sample Depth	0	28.3	56.6	84.9	113.2	141.5	169.8	198.1
84.9		32	31	30	29	28	27	26	25
	Lift 4	52.0	ND	ND	11.5	40.4		32.7	44.3
	Lift 3	17.8	ND	7.3	21.3	14.4	13.8	16.9	68.5
	Lift 2	12.5	15.1	ND	16.3	19.2	ND	11.7	ND
	Lift 1	11.3	20.6	ND	ND	6.5	7.1	15.4	ND
56.6		17	18	19	20	21	22	23	24
	Lift 4	11.5	62.3	46.8	56.5	46.5	26.6	32.6	13.2
	Lift 3	12.1	26.8	12.5	22.1	21.0	18.5	19.1	21.2
	Lift 2	8.8	8.9	24.1	ND	11.2	11.0	7.9	21.4
	Lift 1	7.1	29.8	6.0	9.7	12.8	10.3	ND	18.8
28.3		16	15	14	13	12	11	10	9
	Lift 4	21.3	37.0	37.9	19.0	24.1	18.2	37.4	19.6
	Lift 3	13.9	3.7	18.9	ND	ND	20.2	ND	11.9
	Lift 2	82.3	5.9	ND	26.4		ND	ND	15.6
	Lift 1	12.7	19.5	18.7	12.0	11.3	16.5	ND	8.8
0		1	2	3	4	5	6	7	8
	Lift 4	9.2	28.3	ND	19.3	7.2	13.3	19.5	16.6
	Lift 3	9.7	6.0	14.6	ND	5.5	7.1	10.9	ND
	Lift 2	ND	11.1	20.3	5.8	15.4	ND	9.2	14.5
	Lift 1	9.9	12.2	16.4	12.3	14.0	17.5	17.0	7.3

Table 7. Total Carcinogenic PAHs In The Libby Soil Treatment Facility (mg/kg)

Sampling Date 5/6/91

Sampling Location		Feet South							
Feet East	Sample Depth	0	28.3	56.6	84.9	113.2	141.5	169.8	198.1
84.9		**32**	**31**	**30**	**29**	**28**	**27**	**26**	**25**
	Lift 4								
	Lift 3								
	Lift 2								
	Lift 1								
56.6		**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
	Lift 4								
	Lift 3		121	54	47	12	68	146	97
	Lift 2	49		74	13	44	26	17	16
	Lift 1	46		11	6	26	67	51	23
28.3		**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**
	Lift 4								
	Lift 3	488	75	96	79	341	106	420	163
	Lift 2	49	44	33	32	118	22	123	13
	Lift 1	1049	61	5	39	212	29	101	34
0		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Lift 4								
	Lift 3	34	310	90	233	31	503	63	162
	Lift 2	28	130	29	133	42	176	29	86
	Lift 1	49	58	24	280	19	518	12	161

Table 8. Total Carcinogenic PAHs In The Libby Soil Treatment Facility (mg/kg)									
Sampling Date 9/18/91									
Sampling Location		Feet South							
Feet East	Sample Depth	0	28.3	56.6	84.9	113.2	141.5	169.8	198.1
84.9		**32**	**31**	**30**	**29**	**28**	**27**	**26**	**25**
	Lift 4	352	194	187	131	241		282	247
	Lift 3	53	134	101	83	51	78	79	228
	Lift 2	47	81	84	93	59	66	60	206
	Lift 1	38	74	86	53	35	19	105	23
56.6		**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
	Lift 4	165	352	250	317	201	192	241	110
	Lift 3	165	217	42	160	115	187	88	172
	Lift 2	94	94	117	90	114	129	75	174
	Lift 1	35	232	43	102	22	116	104	117
28.3		**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**
	Lift 4	223	254	150	130	223	172	185	244
	Lift 3	108	370	106	159	193	149	229	151
	Lift 2	357	86	51	124		72	220	71
	Lift 1	116	92	71	131	125	113	68	114
0		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Lift 4	44	187	128	151	17	111	211	134
	Lift 3	81	120	136	63	19	131	150	113
	Lift 2	143	154	274	59	88	172	113	71
	Lift 1	23	116	188	119	151	192	212	68

8.0

REVIEW OF SIX TECHNOLOGIES FOR *IN SITU* BIOREMEDIATION OF DISSOLVED BTEX IN GROUNDWATER

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ABSTRACT

Six technologies which could be applied to effect *in situ* bioremediation of dissolved BTEX contamination resulting from petroleum product releases into groundwater have been reviewed. The six technologies include passive remediation, oxygen addition, addition of acclimated microorganisms, vacuum-vaporizer well (UVB) technique, land surface application of contaminated groundwater, and the subsurface volatilization and ventilation system (SVVS*).

Passive remediation may be appropriate for remediation of dissolved BTEX contamination where biotransformation is occurring naturally. The time required for remediation by natural processes is longer than for active methods. Demonstration of passive remediation is necessary to provide a baseline for evaluating the performance and benefit of other remedial methods.

Oxygen addition to BTEX contaminated groundwater will normally result in BTEX removal via to enhanced biotransformation. The method by which the oxygen is introduced into the subsurface will control the amount of remediation which is due to biotransformation. Methods which use natural dispersive processes to optimize mixing between the oxygenated water and the contaminated groundwater will be most effective.

The addition of acclimated microorganisms to enhance biorestoration of contaminated groundwater is a potentially useful approach, especially in situations where the indigenous microbial population is not capable of performing the desired biotransformation. The addition of oxygen and nutrients is necessary to ensure effective remediation. Limitations of this method include survival of the introduced microorganisms and their lack of transport within the contaminated subsurface environment.

The vacuum-vaporizer-well technique (UVB) incorporates principles of air stripping, vacuum extraction and *in situ* biorestoration to remediate contaminated groundwater. The principal limitations of this method are the suitability of the physical site conditions for establishing circulatory flow of groundwater in the vicinity of the treatment well and adverse chemical interactions due to oxygenation of contaminated groundwater.

Land surface application of groundwater contaminated with dissolved BTEX to shallow, relatively well drained soil environments can result in BTEX removal by biotransformation. This method is designed for treatment of contaminated groundwater pumped from the subsurface and does not directly remediate the contaminated aquifer. This treatment method has potential for economical treatment of large volumes of contaminated groundwater with relatively low dissolved BTEX concentrations.

The subsurface volatilization and ventilation system (SVVS®) combines the approaches of oxygen addition via air sparging within an injection well and removal of contaminant vapours by vacuum extraction to remove dissolved BTEX from groundwater. The principal limitation of this method is the small size of the treatment volume surrounding each well installation. The approach is well suited for treatment of relatively shallow water table aquifers.

1.0 INTRODUCTION

Many technologies are available which claim successful bioremediation of groundwater contaminated by dissolved petroleum products. Benzene, toluene, ethylbenzene and the isomers of xylene (BTEX) comprise most of the soluble fraction of gasoline and are the most abundant, persistent, and potentially harmful compounds associated with petroleum contamination of groundwater. Few methods for bioremediation of groundwater impacted by dissolved BTEX have been subjected to critical evaluation to determine how successful the remediation effort was and to confirm the contribution of various physical processes to the ultimate remediation.

The National Groundwater and Soil Remediation Program (GASReP) has been established to research, develop, and demonstrate innovative remediation technologies. This paper summarizes a review of six technologies for *in situ* bioremediation of groundwater impacted by dissolved BTEX which are being considered for demonstration by GASReP.

The review contains a brief summary of the physical processes responsible for reductions of dissolved BTEX in groundwater and descriptions of the following technologies:

1) Passive remediation,
2) Oxygen addition,
3) Addition of adapted microorganisms,
4) Vacuum-vaporizer-well (UVB) technique,
5) Land surface application, and
6) Subsurface Volatilization and Ventilation System (SVVS®).

The objectives of the review were to:

1) explain how the technology works,
2) identify limitations or constraints of the technology and indicate environments or conditions where the technologies may not work,
3) document the information which may be required from site characterization studies and identify parameters which should be monitored to demonstrate the technologies, and
4) evaluate the performance of the technology in any documented applications.

2.0 PHYSICAL PROCESSES INVOLVED IN *IN SITU* REMEDIATION

Several naturally occurring physical processes can act to reduce dissolved contaminant concentrations in groundwater. These processes include: advection, dispersive mixing, sorptive retardation, volatilization and, biotransformation. *In situ* remediation techniques typically enhance the effects of one or more of these processes to reduce contaminant concentrations. Very few remedial technologies have been demonstrated in a manner which quantifies of the contributions of these processes to observed remediation. It is important that the processes which are responsible for remediation are recognized to ensure that the appropriate remediation approach is selected. The following paragraphs briefly describe the methods by which the above processes act to reduce concentrations of dissolved BTEX in groundwater, naturally and during *in situ* remediation.

Advection is the dominant process responsible for the movement of solutes in an aquifer media, and describes the motion of the solute in response to the movement of groundwater. During *in situ* bioremediation of groundwater advection controls the movement of the dissolved contaminants and the remedial solutions. Advection is generally described by the groundwater velocity (v) which is a function of the hydraulic conductivity (K), hydraulic gradient (i) and the porosity (n) as described by $v = -Ki/n$ (Freeze and Cherry, 1979). In consideration of advection alone, remedial solutions introduced into the contaminated groundwater would tend to displace the contaminated groundwater with minimal mixing and dissolved contaminant concentrations would decrease due to flushing.

Dispersion is responsible for mixing of dissolved solute plumes during transport through an aquifer. The amount of dispersive mixing is a function of the heterogeneity of the aquifer media. Dispersive mixing will be less important in a uniform aquifer, than in a highly heterogeneous aquifer. Diffusion is a dispersive process which results in mixing due to molecular motion caused by thermal kinetic energy of the solutes (Domenico and Schwartz, 1990). Dispersion plays two important roles in *in situ* bioremediation. Firstly, it is a mechanism for reducing dissolved BTEX concentrations. Secondly, it provides a mechanism for mixing dissolved oxygen, or other dissolved solutes with the dissolved BTEX plume.

Sorptive retardation refers to the relative retardation of reactive solutes during transport in an aquifer due to sorption to organic matter or mineral surfaces within the aquifer. For organic solutes the amount of sorption is a function of the solute molecule and the amount of solid organic matter in the aquifer. Sorption will reduce dissolved BTEX concentrations by temporarily removing BTEX from solution. Sorption also determines the relative velocity of individual solutes within an aquifer and can be used to advantage for mixing dissolved contaminant plumes and remedial solutions during *in situ* bioremediation.

Volatilization refers to the partitioning of solute molecules from an aqueous phase to a vapour phase. Volatilization is not an important natural process causing concentration reductions below the water table; however, it is important near and above the water table. BTEX are relatively volatile hydrocarbons and are readily transferred to a vapour phase, thus reducing the dissolved BTEX concentration. This process is used for many remediation technologies which involve sparging air, or oxygen, below the water table.

Biotransformation is the only natural process which reduces dissolved BTEX concentrations in groundwater by physical destruction of the molecule. Aerobic biotransformation of BTEX is a redox reaction which consumes oxygen and produces energy for the microorganism and daughter products (ultimately CO_2 and H_2O). Biotransformation of dissolved BTEX will occur naturally as long as hydrocarbon-utilizing bacteria are present and sufficient oxygen and essential nutrients are available. The amount of oxygen available for natural biotransformation is limited by the solubility of atmospheric oxygen and processes governing the transport and mixing of dissolved oxygen in the aquifer.

In situ bioremediation implies "the enhancement of biological activity in soils and/or groundwater by manipulation of geochemical and/or environmental conditions, and/or addition of selected, adapted, or engineered microorganisms or assemblages of microorganisms, for the purpose of degrading and/or altering the contaminants *in place* (Major, 1991). The principles and controls on biotransformation of dissolved BTEX are only discussed briefly in this paper to illustrate examples for individual technologies. Atlas (1981) and Leahy and Colwell (1990) provide excellent reviews of the technical aspects of biotransformation of petroleum hydrocarbons. Lee *et al.* (1988), Thomas and Ward (1989) and Major (1990) provide a thorough treatment of methods and limitations of *in situ* bioremediation. Madsen (1991) provides a summary of the difficulties and limitations involved in demonstrating and evaluating *in situ* bioremediation.

3.0 PASSIVE REMEDIATION

Passive remediation refers to taking no physical action to reduce known contamination. Remediation thus occurs through the natural action of the processes outlined in Section 2.0. Low capital cost is the principal advantage of passive remediation. The most obvious disadvantage is time. The time restriction has resulted in general disfavour of the passive remediation option among regulatory agencies and public interest groups (Preslo *et al.*, 1988). Research is in progress to demonstrate and quantify the effectiveness of passive remediation to improve the scientific basis for its consideration by regulatory agencies (Bauman, 1991).

In principle, natural processes will eventually cause all incidents of dissolved BTEX contamination to be reduced below levels of concern. The primary control on the time required to achieve this goal is the initial mass of contaminant which has been released. This initial mass will determine the amount of oxygen which is required to effect remediation. The time of remediation will be that required for natural processes to deliver this amount of oxygen. Obviously the source of dissolved BTEX, free phase liquid hydrocarbon, residual liquid hydrocarbon, or hydrocarbon vapour must be removed so that the initial amount of dissolved BTEX is limited. Once the source is removed, the remediation will be controlled by the ability of physical limitations of the site.

The principle of passive remediation is simply that naturally occurring processes of dispersion, sorption, and biotransformation will act to reduce the dissolved contaminant concentrations below levels of concern.

Oxygen delivery is controlled by advection, dispersion, and molecular diffusion in the aquifer. The net effect of these processes is to mix contaminated and uncontaminated groundwater. Groundwater contaminated with dissolved BTEX typically has dissolved oxygen concentrations less than 1 mg/L. The dissolved oxygen concentration in shallow aquifers is typically between 0 and 10 mg/L. Dissolved oxygen concentrations of approximately 10 mg/L imply equilibrium of groundwater and atmospheric oxygen. High natural organic matter contents, physical restrictions on groundwater flow, or metallic oxidants may cause the natural dissolved oxygen concentrations to be less than 10 mg/L.

The rate of passive remediation will be controlled by the natural dissolved oxygen concentration of the groundwater and the hydrogeologic characteristics of the contaminated aquifer which contribute to dispersive mixing. Increased heterogeneity of the aquifer usually results in increased dispersive mixing, and hence faster mass loss rates (MacQuarrie and Sudicky, 1990). Infiltrating precipitation has been demonstrated to increase the concentration of dissolved oxygen at the margin of a dissolved contaminant plume (Wise *et al.*, 1991). This might imply some connection between climatic conditions and expected rates of remediation.

The three significant limitations to passive remediation of groundwater containing dissolved BTEX are:

1) natural biotransformation of dissolved BTEX must be occurring,
2) extremely long times may be required for natural processes to achieve acceptable dissolved BTEX concentrations,
3) the distance which the dissolved BTEX plume could travel during the time required for passive remediation must be less than the distance to the nearest potential receptors.

Groundwater may have naturally low D.O. content due to the presence of organic matter, or reduced mineral or metal species. Petroleum product spills in these environments would undergo very limited and very slow biotransformation. Occasionally the absence of other mineral nutrients such as nitrogen, phosphorus, or trace elements, or the presence of toxic or inhibitory compounds, may limit natural biotransformation of BTEX in the presence of oxygen. In any of these circumstances, passive remediation would not be a suitable remediation alternative. The use of active remediation techniques which would supply the necessary nutrients or to remove toxic or inhibitory compounds would be necessary to effect remediation.

Aerobic biotransformation of dissolved BTEX will occur rapidly when hydrocarbon-utilizing microorganisms and an abundant oxygen supply are present. The biotransformation rate of dissolved BTEX in groundwater will be controlled by the rate at which oxygen is delivered into the contaminant plume by natural mixing processes.

The distance which the dissolved BTEX plume will travel during the course of passive remediation must be less than the distance to the nearest potential receptors for the approach to be acceptable. The most significant receptors are domestic water supplies and surface water discharge. The potential impacts to downgradient receptors must be assessed during the initial decision to proceed with a passive remediation approach. This assessment should include predictive modelling using data collected during detailed site characterizations.

The total cost of implementing passive remediation depends upon the time required for remediation. The capital costs are incurred during the site investigation and installation of the monitoring wells. The remainder of the cost depends upon the scale and frequency of the groundwater monitoring. Frequent monitoring over a long time period may result in total clean-up costs which are larger than would be incurred for enhanced remediation in a short time frame.

An evaluation of passive remediation is an essential component of the demonstration of technologies for *in situ* bioremediation of dissolved BTEX as it serves as a baseline for assessing the benefit of the other remedial methods.

4.0 OXYGEN ADDITION

In situ bioremediation of dissolved BTEX requires that hydrocarbon-utilizing microorganisms, oxygen, nutrients, and dissolved contaminants be in contact. Dissolved oxygen can be introduced into the groundwater as either a liquid or gaseous phase. The four most popular approaches are:

1) injection of aerated/oxygenated groundwater,
2) injection of aqueous hydrogen peroxide mixtures,
3) sparging of air or oxygen into the groundwater through injection wells, and
4) encapsulation of air within colloidal gas apherons (25-50 um surfactant bubbles) which will disperse into the groundwater.

The addition of oxygen, either as dissolved oxygen in groundwater, or in the form of dilute hydrogen peroxide is typically accomplished by means of injection wells or infiltration galleries. Additional hydraulic control is often provided through use of withdrawal wells and recirculation systems which incorporate surface treatment of contaminated water. A schematic illustration of an oxygen delivery system is illustrated in Figure 1.

Although remediation of dissolved BTEX is often reported by users of these four standard oxygen addition approaches, few remedial efforts have quantified the role of biotransformation in *in situ* remediation. Other processes such as advective displacement (flushing), dispersion, sorption, and volatilization may account for a significant portion of the observed concentration reductions.

Most oxygen addition method are limited by the processes which control the mixing of dissolved oxygen into the contaminated groundwater, and geochemical interactions which reduce the availability of dissolved oxygen to enhance BTEX biotransformation.

The tendency for the remedial solutions to displace the groundwater raises doubts about the effectiveness of solution introduction through injection wells for stimulating biotransformation. The mixing of the remedial solutions and hence the opportunity for bioremediation will be a function of dispersion and sorptive retardation.

The use of injection-withdrawal systems as per Raymond (1974) does not overcome this difficulty and, in fact, may provide less mixing than a natural hydraulic gradient. The net result of the injection-withdrawal approach will be a clean portion of aquifer between the injection and withdrawal wells due to flushing by the remedial solutions.

Natural biotransformation of dissolved petroleum products consumes dissolved oxygen and produces anaerobic groundwater. The groundwater geochemistry changes in response to the removal of oxygen and is often characterized by high concentrations of dissolved iron and manganese, elevated concentrations of potentially toxic metals, and reduced sulphur and nitrogen species (Francis and Dodge, 1990). The addition of oxygen will create oxidizing conditions within the aquifer. This will result in oxidation of the reduced iron, manganese and sulphur species and precipitation of iron and manganese oxyhydroxide minerals. These oxidation reactions will compete for available oxygen with the aerobic biotransformation reactions. Remediation will require sufficient oxygen to provide for the biotransformation of the organic compounds and for the oxidation of reduced solutes in the aquifer. The precipitated minerals will occupy part of the porosity in the vicinity of the injection wells and reduce the hydraulic conductivity in this portion of the aquifer. This may eventually restrict the flow of remedial solutions into the contaminated zone.

All forms of organic carbon (solid and dissolved) present in the aquifer can potentially serve as an organic substrate for the microbial population and at least a portion of the uncharacterized organic carbon may be a preferred substrate relative to BTEX. Biotransformation of the uncharacterized organic carbon during *in situ* bioremediation will consume oxygen and nutrients, thus increasing the time and expense required to remediate the dissolved BTEX.

Addition of oxygen in a manner which considers the natural transport and mixing of the contaminated groundwater and the injected solution will maximize the amount and rate of dissolved BTEX removal due to biotransformation. The oxygen addition method being developed by the University of Waterloo (UW) will take advantage of the natural processes of dispersion to mix the remedial solution containing dissolved oxygen and nutrients and the contaminated groundwater. THe implementation of the UW approach will involve optimization of the injection well (or gallery) array and the frequency of injections. The implementation details will be site-specific and will be determined by computer simulation. Two approaches which are being considered are pulsed addition of the remedial solutions and increasing the oxygen infiltration by increased recharge by land irrigation. Preliminary modelling results indicate that pulsed injections will enhance dispersive mixing between the remedial solutions and the contaminated groundwater. Wise *et al.* (1991) have demonstrated that the dissolved oxygen concentrations in contaminated groundwater increased in response to increased infiltration.

5.0 ADDITION OF ACCLIMATED MICROORGANISMS

The addition of microorganisms which are specially adapted, or engineered, to perform the biotransformation of petroleum products has been claimed to enhance remediation of crude oil spills, and for seeding land farming and on-site bioreactors. The addition of acclimated microorganisms to enhance the biotransformation of petroleum products in the subsurface environment was one of the first approaches by which *in situ* bioremediation was conceived. There are many commercial operators who supply microbial consortia for enhanced remediation of petroleum product spills. Most of the commercial approaches involve the addition of oxygen and inorganic nutrients along with the microbial consortia and there is little evidence that the addition of microorganisms has enhanced the biotransformation of the organic contaminants to a greater extent than would be achieved by stimulating the native population by the addition of oxygen and nutrients. The potential for addition of acclimated microorganisms to enhance remediation of petroleum spills beyond the capacity of the indigenous microbial population has not been fully demonstrated (Lee *et al.*, 1988).

The most pertinent question is: "are they necessary?". Subsurface environments contain a diverse microbial population, with many of the microorganisms demonstrating the ability to transform naturally occurring organic compounds (Atlas, 1981). The principle involved in the addition of acclimated microorganisms is that hydrocarbon-utilizing microorganisms may comprise only a minor component of the natural microbial community. The introduction of additional microorganisms prepared in the laboratory would increase the proportion of these microorganisms and should result in enhanced removal of the organic compounds, provided that a lack of oxygen or nutrients does not limit biotransformation. The main issue is whether the natural population of microorganisms with the capability for mediating the desired biotransformation will achieve the same contaminant removal efficiency by the addition of oxygen and nutrients alone.

Hydrocarbon-utilizing microorganisms are common in nature and have been observed to comprise between 0.13% and 50% of the microbial population in subsurface soil. The number of hydrocarbon-utilizing microorganisms is often observed to be higher in soils which have been exposed to hydrocarbons. For this reason the natural microbial community can be assumed to have the capacity to perform the biotransformation of dissolved BTEX, and that the addition of acclimated microorganisms would be beneficial only when attempts to stimulate the natural population by the addition of nutrients have failed, or when characterizations of the natural microbial population demonstrate that microorganisms with the required abilities are not present (D. Major, personal communication, 1991).

Microorganisms with the specific capability to mediate the transformation of petroleum hydrocarbons are normally isolated in the laboratory using enrichment culturing techniques, or created by genetic manipulation. Three potential sources of microorganisms are:

1) unimpacted surface or subsurface soils or groundwater,
2) impacted surface or subsurface soils or groundwater (leachates), and,
3) biological treatment facilities.

Enriched cultures derived from natural microbial populations at the site are preferred for addition into the subsurface environment since these microorganisms should be adapted to the subsurface environmental conditions of the site and thus have a greater potential for survival. Cultures derived from the contaminated soils or groundwater have an advantage over cultures from unimpacted areas because they have already been exposed to the contaminants and would be less likely to suffer toxic effects from the contaminants. Cultures derived from biological treatment facilities may not be suitable for introduction into the subsurface as they are not adapted to low temperatures and the oligotrophic subsurface environment and theoretically have lower potential for survival. Most commercially available mixtures of acclimated microorganisms have been cultured from other contaminant sites or treatment facilities. The potential for survival, and hence the performance of these cultures may vary in response to site specific conditions.

A more recent development is the application of genetic engineering to modify the capabilities of microorganisms to perform specific biotransformation reactions thus creating Genetically Engineered Microorganisms (GEMS). For example, genetic information, in the form of coded plasmid DNA, is commonly transferred from an organism with the desired biotransformation capabilities into another organism. The genetic manipulation can be used to stabilize the degradative traits coded by the plasmid, increase the number of plasmids in a cell, amplify enzyme production and activity, invoke multiple degradative traits, or produce a novel degradative pathway (Lee *et al.*, 1988). Enhanced bioremediation via the addition of GEMS to the subsurface depends upon the survival of the introduced microorganism and the maintenance of the engineered capability within the introduces organism (Jain *et al.*, 1987).

The addition of acclimated microorganisms is typically performed using an injection well screened below the water table and positioned within the contaminated zone (Figure 1). Some systems may use infiltration galleries to introduce the remedial solutions. Oxygen and limiting inorganic nutrients, such as nitrogen and phosphorus, are normally added along with the microorganisms. This method of introduction has disadvantages such as advective displacement of contaminated groundwater and limited mixing between the remedial solutions and the contaminated groundwater.

The principal limitations of the addition of acclimated microorganisms relate to the survival of the introduced bacteria, the distribution and transport of microorganisms within the subsurface environment and ensuring that the microorganisms retain their specific biotransformation abilities (Wilson *et al.*, 1986; Major, 1991). Relatively little information is available describing the distribution of microorganisms in the subsurface, and especially describing the transport of microorganisms in groundwater. This lack of knowledge creates considerable uncertainty in the advantages of this approach. Perhaps more significant concerns relate to the difficulties encountered in ensuring adequate delivery of oxygen and nutrients to the microbial population.

For any remedial effort involving the addition of acclimated microorganisms to be successful the introduced microorganisms, or at least the desired genetic capability, must be able to survive and flourish under the subsurface environmental conditions. The potential for survival of microorganisms which have been cultured or created under laboratory conditions in natural subsurface environment is undetermined and will be site specific. Microorganisms are extremely sensitive to the environmental conditions of their habitat. Environmental factors which influence the survival of microorganisms include: pH; pO_2; temperature; redox potential; sources of organic carbon; presence of essential nutrients; organic and inorganic toxins; presence of predators; and competition between microbial populations (Fewson, 1988).

6.0 VACUUM-VAPORIZER-WELL (UVB) TECHNIQUE

The Vacuum-Vaporizer-Well (German: Unterdruck-Verdampfer-Brunnen, abbreviation: UVB) technique has been developed in Germany and applied successfully for the remediation of groundwater contaminated by volatile organic compounds. The method combines principles of air stripping, vacuum extraction, hydraulic control, and *in situ* biotransformation to achieve aquifer remediation. This combination of approaches overcomes many of the problems which arise with other aquifer remediation methods. Descriptions of the theory and application of this method in Germany are available (Herrling *et al.*, 1991, 1990a,b; Buermann, 1990 a,b).

The UVB technique uses a combined injection-withdrawal well and incorporates *in situ* air stripping and vacuum extraction technologies to generate recirculatory flow of groundwater in the vicinity of the UVB well. Dissolved BTEX remediation will occur through:

1) removal of the contaminated groundwater for surface treatment,
2) removal of volatile compounds by air stripping the groundwater within the UVB well and recovery of the stripped contaminants at surface by conventional vacuum extraction and carbon adsorption treatment, and
3) enhanced *in situ* biotransformation under aerobic conditions created within the recirculation zone of the UVB well.

The features of the UVB well as shown in Figure 2 include:

- screened intervals in the well at the base of the aquifer (or zone of contamination) and at the water table;
- an impermeable seal between the well and borehole annulus to reduce short circuiting of the recirculating groundwater;
- isolation of the upper and lower portions of the well and hydraulic connection via a submersible pump to draw water from the lower section into the upper section;
- a mechanism for introducing air or gases into the water column within the well to create the *in situ* air stripper, and
- a ventilator for withdrawal of contaminated vapours from *in situ* groundwater treatment and the unsaturated zone followed by surface treatment via carbon adsorption.

Groundwater is drawn into the lower screened interval and pumped into the upper chamber of the UVB well. Air or gas mixtures are introduced into the water column in the upper chamber by sparging. The combined effects of the pumping and the air sparging cause the water table to rise, within and around the well, and forces the groundwater to re-enter the aquifer through the upper screened interval. A vacuum is maintained on the borehole annulus to draw the sparged air and air from the unsaturated zone to the surface for treatment. The water entering the aquifer through the upper screened interval has been aerated by the air stripping and, under conditions of no horizontal flow within the aquifer, the hydraulics of the system would cause all of the treated water to be captured by the lower screened interval and be recirculated through the well.

Enhanced *in situ* bioremediation of organic compounds under aerobic conditions will occur within this zone of recirculation when oxygen is a component of the sparged gas. The effectiveness of the treatment is dependant on the volatility and concentrations of the dissolved organic compounds, the relative rates of pumping and aeration, and the hydraulic properties of the aquifer. Modifications to the system can include additions of chemicals to reduce the effects of well clogging due to oxidation within the zone of air stripping, or for addition of limiting nutrients for the indigenous bacteria. These modifications may also reduce the potential for mineral precipitation and clogging within the contaminated aquifer.

An obvious advantage of the UVB method is the recirculation and treatment of contaminated groundwater without the need for withdrawal and surface treatment or the need for permission to reinject groundwater into the aquifer. This recirculation is extremely important for *in situ* bioremediation as the difficulties of introducing oxygen and limiting nutrients and ensuring mixing within the aquifer limit most remedial designs. The UVB is especially adapted for oxygenation of groundwater (either by addition of air or pure oxygen) to enhance aerobic biotransformation, such as the biotransformation of BTEX.

The factors which may contribute to limit the success of this method include the physical properties of the contaminants, the hydrogeologic setting, and the natural groundwater chemistry. Application of this method to take advantage of potential biotransformation also requires that favourable environmental conditions be created and maintained.

Air stripping is the dominant process by which the UVB removes organic contaminants from groundwater. BTEX are relatively volatile compounds and can be removed readily by the UVB method.

Successful operation of the UVB well depends upon the hydrogeologic conditions of the impacted aquifer which determine the zones of influence and capture for the UVB well. Site-specific properties which will influence the design and operation of the UVB are: contaminated aquifer thickness; stratigraphic uniformity; hydraulic conductivity, and groundwater velocity. Design factors such as screen lengths and positions, and air and groundwater pumping rates can be adjusted to optimize the remediation with respect to the physical setting. The effects of natural groundwater velocity on the physics of the recirculation cells requires that one pass through the UVB well be sufficient to remove contaminants to the desired clean-up criteria.

The natural groundwater chemistry can provide significant limitations to the operation of the UVB by causing corrosion of the well materials or precipitation of mineral phases within the well, filter packs, or the aquifer. The operation of the UVB well introduces oxygen into the impacted groundwater. One effect of this addition will be to cause reaction between any oxidizable materials (such as iron, or galvanized steel) which may be used to construct the

UVB well. This reaction may result in failure of pump parts, increase in the diameters of the orifices of the sparger equipment, or corrosion of the well screen. The precipitation of mineral phases can severely limit the efficient operation of the UVB well. The UVB well can be modified to permit addition of other chemicals such as ascorbic acid which will reduce these effects.

7.0 LAND SURFACE APPLICATION

Land surface application has been investigated as a potential method for disposal and treatment of groundwater impacted by dissolved BTEX through a series of laboratory and field experiments conducted by the University of Waterloo (Allen *et al.*, 1987; 1989; 1991). The application of impacted groundwater to the soil surface as a treatment method has not yet been employed as a regular practice by the industry. Experimental results to date indicate that a controlled remedial demonstration at an existing contaminated site is warranted.

The following discussion will be limited to the land surface application portion of this remedial approach and will not address the removal of contaminated groundwater from the contaminated aquifers which is normally accomplished by traditional pumping methods such as described in Mercer *et al.* (1990). Land surface application is seen as an alternative to other on-site treatment methods such as carbon adsorption, air-stripping, and photo-oxidation. An advantage of land surface application for treatment of dissolved BTEX is that the contaminants are transformed to innocuous products (CO_2 and H_2O) by the action of the microorganisms.

Optimum conditions for the biotransformation of dissolved BTEX can be created in unsaturated soil columns. Indigenous hydrocarbon-utilizing bacteria are present in the soils, oxygen is abundant, and water and dissolved BTEX can be applied to the surface in a manner that will permit infiltration through the soil column. The dissolved BTEX will be removed by biotransformation as the water infiltrates through the column. The treatment system must be designed to minimize volatilization to the atmosphere during groundwater application and to ensure that dissolved BTEX does not contaminate groundwater beneath the treatment site. A schematic illustration of land surface application is provided in Figure 3.

The main requirement of a site for application of land surface treatment is an unsaturated soil horizon. Groundwater with dissolved BTEX (and possibly nutrients) is applied to the land surface by methods which provide for uniform areal application and minimize volatilization. The application rate must not cause saturation of the soil column. In an unsaturated condition oxygen will be able to diffuse into the active zone of bioremediation via the soil vapour phase and oxygen availability will not likely limit the biotransformation. Under saturated conditions the rate of oxygen availability will be determined by oxygen transport by advection and dispersion. The contaminant loading and nutrient requirements are also significant factors controlling the design of the remedial system.

The physical site characteristics which will influence the success of land surface application of BTEX contaminated groundwater include depth to water table, distribution of heterogeneities within the unsaturated zone, soil type, and soil organic matter content.

The dissolved BTEX loading must be maintained at a level which does not exceed the oxygen supply. Under unsaturated conditions this has not been a significant problem in the laboratory column experiments (R. Allen, personal communication). The oxygen gas concentrations in the soil vapour phase are reduced in areas where active biotransformation is occurring, but the consumed oxygen is replaced by diffusion, hence, oxygen availability does not limit biotransformation. Other uncharacterized organic matter (solid and dissolved) and reduced species such as iron must be considered in the determination of the total oxygen demand as reactions involving these compounds will reduce the amount of oxygen available for biotransformation of dissolved BTEX.

The biotransformation of petroleum products by soil bacteria requires that inorganic nutrients such as nitrogen and phosphorus be available to support the increased growth of the microbial populations. These compounds are typically present only in small quantities in natural groundwater and their consumption may quickly limit the performance of the enhanced bioremediation attempt. Laboratory studies by Allen *et al.* (1991) have demonstrated that the addition of mineral nutrients to the applied groundwater increased the rate of dissolved BTEX removal in the lower portion of the soil profile where the organic matter and nutrient concentrations are naturally lower. Nitrogen is considered to be the most significant nutrient, whose absence responsible for limiting the biotransformation in the nutrient poor soil horizon (Allen *et al.*, 1991). If inorganic nutrients are added the nutrient concentrations must be sufficient to enhance biotransformation but not be so high as to inhibit the biotransformation reactions, be toxic to the microbial population, or cause groundwater contamination.

Tests to evaluate the compatibility of the contaminated groundwater and the native microbial population, and to identify potential inhibition of the desired biotransformation reactions are recommended prior to full-scale implementation of the treatment system.

Microbial activity is temperature sensitive and is generally reduced at lower temperatures. The potential use of the land application method may be limited in cold climates for two reasons. Firstly, the groundwater application and infiltration system will be difficult to maintain under frozen ground conditions. Secondly, the reduced microbial activity may cause persistence of dissolved BTEX and hence contamination of the underlying groundwater. The suspension of land application operations during winter conditions may require an additional acclimation period on re-initiation during the spring.

Research by Allen *et al.* (1991) has shown that land surface application on a 5 x 5 m soil plot at a rate of 8500 L/day can potentially remove up to 29 mg/L of toluene dissolved in groundwater. This approach is best suited for treating relatively large volumes of groundwater with low concentrations of dissolved contaminants.

8.0 SUBSURFACE VOLATILIZATION AND VENTILATION SYSTEM®

The Subsurface Volatilization and Ventilation System® (SVVS®, patent pending 1989) is a novel technology which combines the principles of vapour extraction, *in situ* bioremediation, and *in situ* air stripping to remediate subsurface soils and groundwater impacted by petroleum hydrocarbons. The SVVS® has been designed and developed by Billings and Associates in Albuquerque, New Mexico. The SVVS® technology has been applied to remediate several sites in shallow water table aquifers in New Mexico under direction of the Albuquerque Environmental Health Department and the New Mexico Environmental Improvement Division. The theory and operation of the SVVS® has been described by Ardito and Billings (1990).

The technology consists of a series of nested well installations strategically placed within the zone of contamination. Each nested well location includes a vapour extraction well screened within the unsaturated zone above the water table, and an air injection well screened below the water table within the zone of dissolved contamination. A schematic illustration of the components of the SVVS* is provided on Figure 4.

Air is introduced into the dissolved BTEX plume through the injection wells resulting in increased dissolved oxygen concentrations in the groundwater, and also causing partitioning of dissolved BTEX to the sparged air phase which moves to the water table and is then retrieved through the vapour extraction well. The increased dissolved oxygen availability should stimulate biotransformation of the dissolved BTEX by the indigenous bacterial population.

The SVVS* has been designed specifically for restoration of shallow aquifers contaminated by petroleum products. Because it is a hybrid technology, it is very difficult to differentiate the effects of the processes of volatilization and biotransformation which act together to achieve aquifer remediation. Successful remediation using the SVVS* requires free movement of soil gases within the unsaturated zone, efficient partitioning of volatile compounds into the air phase within the aquifer, and efficient dissolution of oxygen into the groundwater from the sparged air.

The effectiveness of the SVVS* depends upon the design and physical operation of the system in response to the site specific subsurface environment and the type and distribution of contamination. The factors which influence the SVVS* design and operation can be grouped according to site characteristics, contaminant type, and design and operational parameters.

For effective operation the site should have a sufficient unsaturated thickness above the water table for installation and effective operation of the vacuum extraction well. The GASReP review of soil vapour extraction applications suggests that vacuum extraction may be implemented where the unsaturated zone is as thin as 1.2 m (CH_2M Hill, 1990).

Stratigraphic variability, and the potential for individual units to become saturated can reduce the mobility of the vapour phase in the unsaturated zone. As an example, fine grained layers, such as silts or clays, within the unsaturated zone will tend to have a higher residual moisture content and may in fact be close to saturation which would potentially decrease the ability for gas phases to transport through this layer. Although the presence of impermeable units within the unsaturated zone will tend to reduce the effectiveness of the SVVS*, the presence of an areally extensive impermeable barrier at surface, or within the unsaturated zone will improve the recovery efficiency of the vapour extraction system. Stratigraphic variability below the water table may influence the performance of the SVVS* by limiting the movement of sparged air to more permeable pathways.

The SVVS* is most effective for removal of volatile and soluble petroleum components, such as BTEX, from contaminated groundwater. The SVVS* will cause some enhancement of naturally occurring aerobic biotransformation processes in the zone of oxygenated groundwater and within the unsaturated zone. Normal operation of the SVVS* does not include the addition of inorganic nutrients whose absence could limit *in situ* bioremediation, although there is potential to effect this modification. Biotransformation assessments of the indigenous microbial population, including possible nutrient limitations or toxicity and monitoring of the biotransformation reactions during SVVS* operation are necessary to ensure that the remediation potential is fully realized.

The successful application of the SVVS* is integrally dependant upon site specific design and operation criteria. The significant design parameters include spacing of the well nests, the relative lengths and positions of the vapour extraction and air injection well screens, vacuum pressure, and air injection flow rates. An advantage of the SVVS* is its flexibility which permits adjustment of the operational parameters to optimize performance in response to observations. The positions of the nested wells will be determined by the distribution of contamination and the clean-up objectives of the remediation program.

The use of the SVVS* to enhance bioremediation requires that oxygen become dissolved into the groundwater, or residual pore water in the unsaturated zone, where it can be utilized by the microbial population. Efficient oxygen transfer between the injected air phase and the groundwater is important. This process will be controlled by the injection pressure, oxygen content of the injected gas phase, and aquifer properties such as hydraulic conductivity, porosity and groundwater velocity. Optimal operation of the SVVS® will occur when these parameters are adjusted to allow saturation of the groundwater with respect to dissolved oxygen while maintaining low gaseous contents within the aquifer.

Groundwater which has been impacted by petroleum products will be anaerobic and characterized by elevated concentrations of dissolved iron and manganese (Francis and Dodge, 1990). Introduction of oxygen into this environment will result in mineral precipitation, and may potentially cause a severe reduction of the hydraulic conductivity within the aquifer surrounding the injection well. This reaction also consumes dissolved oxygen which would otherwise be available for biotransformation. Continued oxygen addition in these conditions may reduce the efficiency of the remedial operation. The limitations of mineral precipitation and oxygen consumption by inorganic redox reactions have not been observed to limit the SVVS® performance at typical operating rates (C. Ardito, personal communication). However, these interactions have not been studied in detail in the applications to date.

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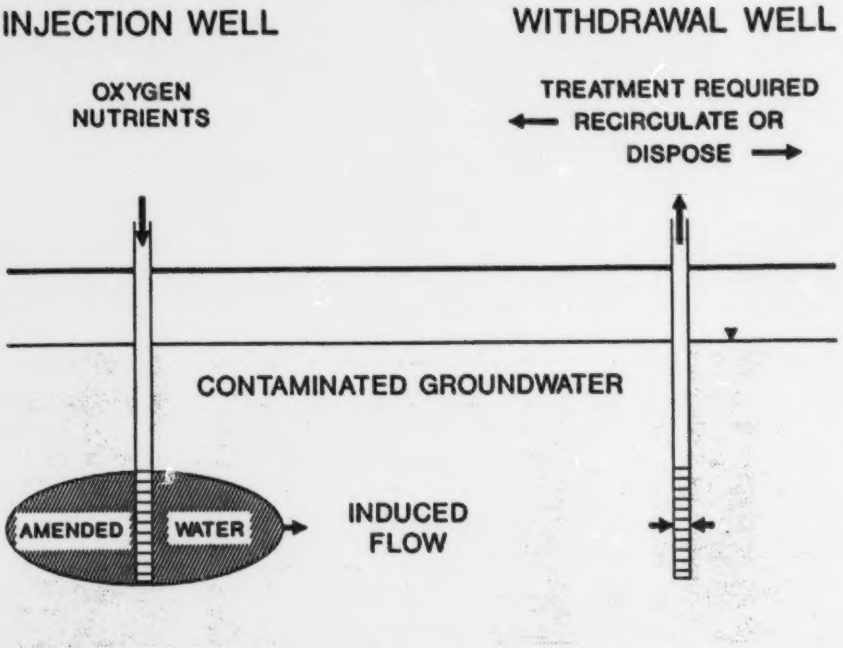
INJECTION WELL
WITHDRAWAL WELL
OXYGEN
NUTRIENTS
TREATMENT REQUIRED
RECIRCULATE OR
DISPOSE
CONTAMINATED GROUNDWATER
AMENDED
WATER
INDUCED
FLOW

Figure 1. Schematic of typical system for introducing oxygen and nutrients into the subsurface.

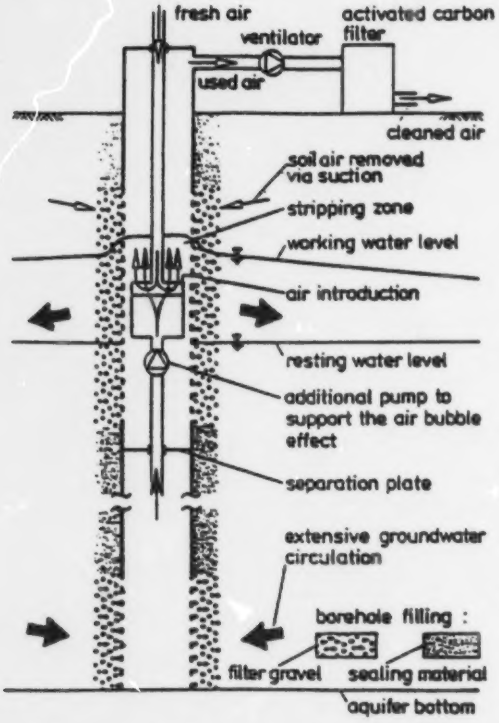
fresh air
activated carbon filter
ventilator
used air
cleaned air
soil air removed via suction
stripping zone
working water level
air introduction
resting water level
additional pump to support the air bubble effect
separation plate
extensive groundwater circulation
borehole filling :
filter gravel
sealing material
aquifer bottom

Figure 2. Schematic illustration of UVB well (from Herrling, 1990a).

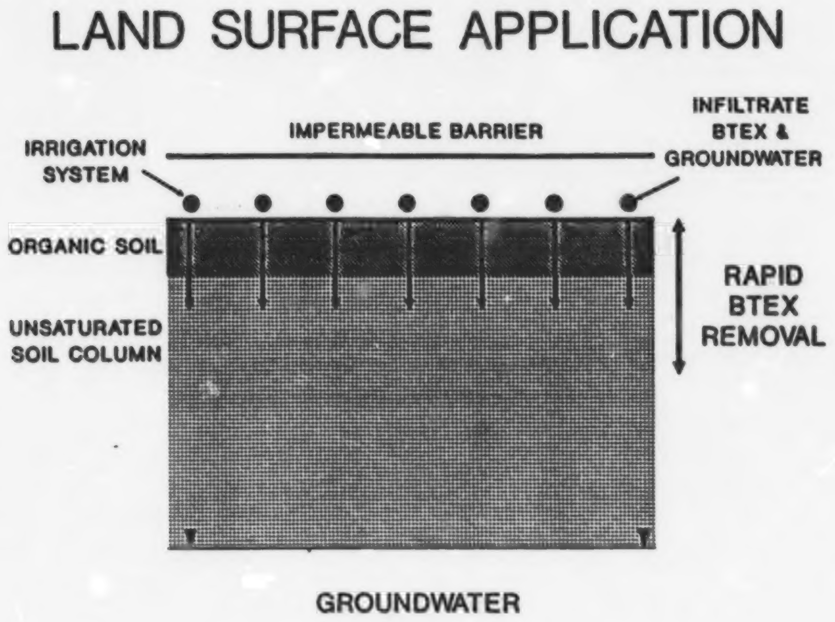
LAND SURFACE APPLICATION
IMPERMEABLE BARRIER
INFILTRATE BTEX & GROUNDWATER
IRRIGATION SYSTEM
ORGANIC SOIL
UNSATURATED SOIL COLUMN
RAPID BTEX REMOVAL
GROUNDWATER

Figure 3. Schematic illustration of land surface application of dissolved BTEX.

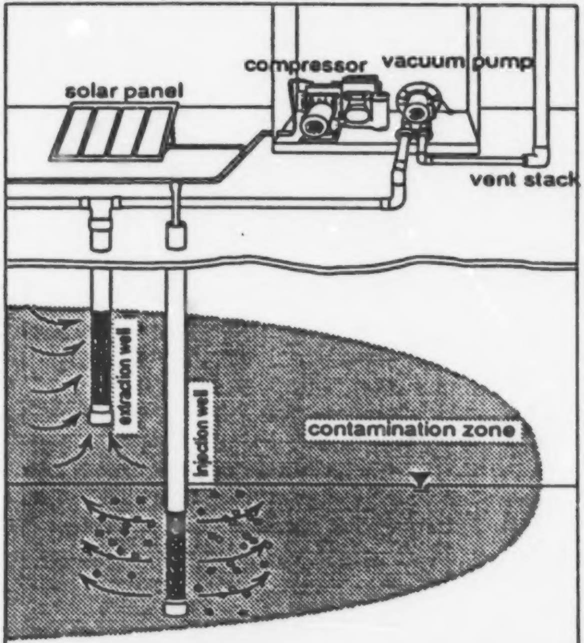
solar panel
compressor
vacuum pump
vent stack
extraction well
injection well
contamination zone

Figure 4. Schematic illustration of the components of the Subsurface Volatilization and Ventilation System (SVVS™) (from Ardito and Billings, 1990).

ACKNOWLEDGEMENTS

This paper was condensed from a report entitled "Review of Six Technologies for *In Situ* Bioremediation of Dissolved BTEX in Groundwater" by L.A. Lemon, Dr. J.F. Barker and Dr. B. Butler. This research was completed with financial support from the National Groundwater and Soil Remediation Program (GASReP). The authors acknowledge the constructive review and comment of Rob Booth and Alex Lye of the Wastewater Technology Centre (Environment Canada), Burlington, Ontario for direction and comments during the preparation of this report. The authors would also like to thank Dave Major of Beak Consultants, Guelph, Ontario; Drs. Werner Buermann and Bruno Herrling of The Institute of Hydromechanics, University of Karlsruhe, Germany; Dr. Peter Brinnel of Hydrodata, Oberursel, Germany; Cindy Ardito, Intera, Albuquerque, New Mexico; Jeff Billings, Billings and Associates, Albuquerque, New Mexico; and Bruce Bauman, American Petroleum Institute, Washington, D.C. for information, helpful discussions, and critical review of individual sections.

BIOGRAPHICAL SKETCH

Lloyd A. Lemon received a Masters of Science (Earth Science) from the University of Waterloo. He was employed as a research co-ordinator for Dr. James Barker by the Waterloo Center for Groundwater Research between 1988 and 1991 and participated in several research projects to investigate the fate and behaviour of dissolved petroleum products in groundwater. He is currently employed as a hydrogeologist by Jacques Whitford Environment Limited in Fredericton, New Brunswick.

9.0

IN-SITU, ON-SITE BIOREMEDIATION OF WOOD TREATMENT SOILS CONTAINING CHLORINATED PHENOLS AND PAHs

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ABSTRACT

Field research was conducted to evaluate the influence of organic soil amendments and bacterial inoculation on in-situ and on-site bioremediation of wood-treatment soils containing chlorinated phenols and polycyclic aromatic hydrocarbons (PAHs). Soil in twenty-one in-situ plots, each covering an area of approximately 10 m^2, was treated to a depth of 0.6 m. A single on-site plot composed of a synthetic liner covered by a steel/polyethylene structure was prepared to allow treatment of excavated soil with high concentrations of chlorinated phenols and PAHs. Soils treatments included tillage, solid-phase organic amendments, and pure culture bacterial inoculation utilizing an indigenous strain of Pseudomonas resinovorans that was isolated on-site. Preliminary results indicated that, during the 11 weeks following imposition of treatments, rapid biodegradation of pentachlorophenol (PCP) and PAHs occurred in the in-situ plots that received the organic amendments alone or in combination with bacterial inoculation. The concentration of PCP in soil treated with the organic amendment decreased to below the proposed soil remediation guideline for industrial soil. A reduction in PCP concentration was also observed in soil that was inoculated without addition of the organic amendment, however, the residual PCP concentration remained greater than the proposed guideline. Excavated soil treated with an organic amendment and inoculated also supported extensive biodegradation of PCP and PAHs. During the 21 days following treatment, the soil's PCP concentration was reduced from 669 mg/kg to 349 mg/kg. Laboratory microcosms containing treated soil taken from the on-site plot supported rapid mineralization of added ^{14}C-PCP, thereby verifying that the observed reduction in PCP concentration was due to biodegradation.

9.1

IN-SITU, ON-SITE BIOREMEDIATION OF WOOD TREATMENT SOILS CONTAINING CHLORINATED PHENOLS AND PAHs

INTRODUCTION

Bioremediation is a preferred means of remediation for soil contaminated with toxic organic chemicals because it can provide a final solution through decomposition of the target compounds to acceptable concentrations. In addition, bioremediation is often the most cost-effective method for remediation of large quantities of contaminated soils. The use of some currently available soil remediation technologies has been limited by their cost. Application of bioremediation to the clean-up of soils contaminated with chlorinated phenols, particularly pentachlorophenol, has been limited by the acute toxicity of the target compound. Pentachlorophenol is an uncoupler of oxidative phosphorylation, and as such is toxic to the microorganisms that degrade it.

Industrial wood-treatment processes usually employ a 5% solution of technical grade pentachlorophenol in mineral oil or creosote, which is mainly composed of polycyclic aromatic hydrocarbons (PAHs). A portion of the treatment solution may be deposited to soils at wood-treatment facilities, rendering the soil matrix hydrophobic and toxic. In addition, many pores in the soil matrix, which previously held biologically available air and water, may become filled with the oil/chlorinated phenol solution or creosote. In such soils, establishment of an active population of chlorophenol-degrading microorganisms can be difficult.

A variety of toxic organic compounds can be degraded by soil bacteria[1-8]; however the rate at which biodegradation proceeds is often limited by physical and chemical conditions within the soil matrix. Rapid biodegradation of pollutants reduces the potential for their partitioning to less environmentally acceptable fates such as bioaccumulation or migration to groundwater. Microbial activity in soil is not evenly distributed throughout the soil matrix. Instead, it is concentrated at microsites where the combination of environmental variables (e.g. oxygen tension, biologically available water, nutrient supply, surfaces for adhesion, toxicity) is suitable for microbial growth. In polluted soils, a variety of factors can limit the number of microsites where microbial growth can occur, thereby limiting the size and activity of the soil's microbial population. Traditional approaches to bioremediation, which attempt to improve soil conditions by aeration, addition of inorganic nutrients and water, are often ineffective and unpredictable, particularly in soils contaminated with toxic, hydrophobic, organic compounds.

Technical Background

Research conducted by Dearborn Environmental Consulting Group at Environment Canada's Wastewater Technology Centre in Burlington, Ontario has demonstrated that bioremediation of soils contaminated with high concentrations of chlorinated phenols and PAHs can be achieved by addition of solid-phase organic amendments of specific particle-size and nutrient content. The bench-scale research demonstrated that the organic soil amendment technology can be used to bioremediate a wide range of wood-treatment soils. Treatment of soil with the organic amendment facilitated establishment of active populations of PCP-degrading bacteria in soils with concentrations of PCP as high as

2170 mg/kg. Previous studies in the United States[9] indicated that soils containing more than approximately 300-400 mg PCP/kg may be too toxic for direct bioremediation, requiring other preliminary treatments such as soil washing. Soils at wood treatment facilities can contain significantly more than 400-500 mg PCP/kg, therefore the increased survival of PCP-degrading bacteria introduced to highly contaminated soil treated with the organic amendment may render bioremediation applicable to more wood-treatment soils and wastes.

Equally important is the observation that residual PCP concentrations in soils treated with the new technology are significantly lower than those reported in the literature. Persistent residual PCP concentrations of 10-50 mg/kg are often reported[9,10]. Results from the bench-scale research program indicate that low residual PCP concentrations (0.7 mg/kg to 8 mg/kg) can be attained for soils treated with the patent-pending technology. Representative data from the bench-scale work, employing the organic amendment, are presented in Figure 1. In most soils the combination of organic amendment and bacterial inoculation was more effective for increasing biodegradation of PCP than either the amendment or bacterial inoculation alone. Other bench-scale work indicates that the same organic soil amendments can be used to enhance microbial decomposition of PAHs.

The organic amendment technique has been successfully applied to eight soils from wood-treatment sites located in British Columbia, Ontario, Quebec and Newfoundland. Mass balance studies indicate that pentachlorophenol is degraded to concentrations below current guideline concentrations with release of chloride ion and carbon dioxide. No products of partial degradation of PCP (metabolites) were detected. A significant reduction in toxicity of highly contaminated wood-treatment soil (1365 mg PCP/kg) in response to treatment with the organic amendment has also been verified by the MICROTOX™ bioassay (Table 1).

Phase partitioning investigations in which the organic amendments were added to industrial wood-treatment soil indicate that PCP is adsorbed by the organic materials and that aqueous-phase PCP concentrations, and hence acute toxicity to microorganisms, are greatly reduced (Figure 2).

MATERIALS AND METHODS

Site Selection

The field research program includes set-up and maintenance of in-situ and on-site research plots at an industrial wood-preserving facility. Site selection was based on soil analysis which indicated the presence of significant concentrations of chlorinated phenols and PAHs.

In-situ Plots

The experimental design, which includes one control and six treatments, allows determination of the influence of each treatment on biodegradation of the target compounds as well as separation of the effects of tillage and bacterial inoculation. Natural rates of soil remediation were determined by monitoring target compound concentrations in control plots where soil remained undisturbed and no treatments were applied.

The treatments employed were:

(1) tillage
(2) tillage and bacterial inoculation
(3) tillage and low nutrient-content organic amendment
(4) tillage, bacterial inoculation, and low nutrient-content organic amendment
(5) tillage, bacterial inoculation, low nutrient-content organic amendment and controlled-release inorganic nutrients
(6) tillage, bacterial inoculation and high nutrient-content organic amendment

All treatments and the control were replicated three times, resulting in establishment of twenty-one square plots, each covering an area of 10 m^2. Based on a tillage depth of 0.6 m and a bulk density of 1.4 g/cm^3, each plot contained approximately 8.4 tonnes of treated soil. Plots were surrounded by a zinc-plated metal perimeter installed to a depth of 0.15 m to prevent run-on and run-off of treatment materials and target compounds. An undisturbed buffer zone (2.0 m) surrounded each plot. Selection of organic soil amendments and application rates were based on the results of bench-scale biodegradation investigations.

Tillage, to a depth of 60 cm, was performed every two weeks with a power take-off driven mechanical rotary tiller. Inoculated plots were always tilled last to prevent transfer of the organism used for inoculation. The tiller was cleaned between tilling of each treatment to minimize transfer of amendments, nutrients or inoculum.

After addition of soil amendments the water holding capacity

(WHC) of soil in each plot was determined. Irrigated was performed as required to maintain soil water content near 80% of WHC. By maintaining soil moisture content at a value less than the WHC, increased solute migration was minimized.

On-Site Plot

The on-site research plot was constructed utilizing a synthetic (high density polyethylene) liner and covered by a steel/transparent polyethylene structure. The enclosed area was electrically heated to allow continuation of the work through the fall and winter. Approximately twelve tonnes of soil was excavated from an area near the wood-treatment apparatus and transported to the on-site plot and spread to a depth of approximately 0.5 m. The soil contained higher concentrations of chlorinated phenols and PAHs, approximately 600 mg/kg and 1400 mg/kg respectively. The treatment applied to soil in the on-site plot consisted of pure culture bacterial at a density of 7×10^5 cells/g soil and low nutrient content organic amendment. Soil moisture was set to 80% WHC by trickle irrigation. Soil temperature was maintained at 18-26°C.

Microbiology

Twelve of the in-situ plots and the on-site plot were inoculated with a pure culture of PCP-degrading bacteria at a density of 2.5×10^5 cells/g. The ability of the culture to degrade PCP was established by evolution of ^{14}C-CO_2 from aqueous cultures supplemented with ^{14}C-PCP. The organism was isolated by enrichment culture (set-up on-site) utilizing soil collected from the plot area. The organism was identified as a strain of Pseudomonas resinovorans. Inoculum was added directly to the soil as an aqueous cell suspension of known cell density. Treatments that were not inoculated received an equal volume of the same sterile medium used to produce the inoculum.

Toxicity Testing

The influence of bioremediation on soil toxicity can be evaluated through the use of the Microtox^R procedure (Bulich[11]). Soil samples were collected to allow evaluation of the effect of each treatment on soil toxicity as estimated by Microtox^R.

Organic Analyses

Determination of target compound concentrations in soil were performed by the Laboratory Services Division of the Wastewater Technology Centre, according to validated protocols. Chlorinated phenols were quantified by solvent extraction and electron capture gas chromatography. PAH concentrations were determined by soxhlet extraction and gas chromatography/mass spectroscopy.

RESULTS AND DISCUSSION

In-Situ Plots

Preliminary data indicate sharp reductions in pentachlorophenol concentrations during the 11 week period following application of treatments to soil in-situ (Table 2). In plots that received organic amendment alone, or in combination with bacterial inoculation, mean soil PCP concentrations were reduced to below the interim remediation guideline (5 mg/kg) for commercial and industrial soils, as established by the Canadian Council of Ministers of the Environment (CCME). The PCP concentration in soil that was tilled and inoculated but did not receive organic amendment was also reduced; however, it remained above the interim remediation guideline. Approximately the same PCP concentration was present in the control soil after eleven weeks as at the initial sampling.

On-Site Plot

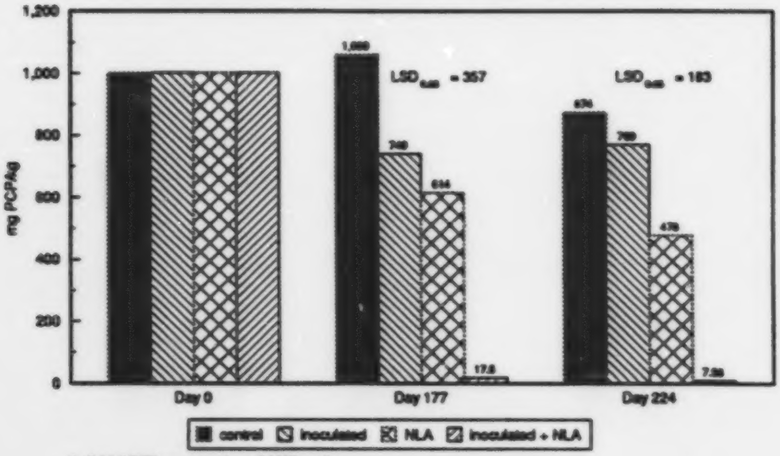
Preliminary data from the first post-treatment sampling of the more highly contaminated soil contained in the on-site plot is presented in Table 3. The data indicates rapid biodegradation of chlorinated phenols with a 49% reduction in the total chlorophenol concentration. The PCP concentration was reduced from 669 mg/kg to 336 mg/kg. Concentrations of most chlorophenol isomers also decreased during the first 21 days of treatment. Observed increases in concentrations of some isomers (e.g. 2,3-dichlorophenol, 2,3,4,5-tetrachlorophenol) may be due to partial dechlorination of more highly chlorinated phenols.

The assumption that observed reductions in chlorinated phenol concentrations was caused by biodegradation (as opposed to other processes such as volatilization or adsorption) was tested by monitoring evolution of ^{14}C-CO_2 from treated soil that was taken from the on-site plot, transferred to laboratory microcosms, and supplemented with ^{14}C-PCP. During the first 48 h following set-up of the microcosms more than 12% of the added ^{14}C-PCP was recovered as ^{14}C-CO_2 (data not presented), verifying ring-cleavage and biodegradation of the chemical.

Rapid biodegradation of PAHs was also observed in soil contained by the on-site plot (Figures 3a and 3b) during the 21 days immediately following inoculation, irrigation, and addition of the organic amendment. Large differences in the rates of decomposition of specific PAH isomers were observed. Among the PAHs with initial concentrations greater than CCME guidelines for industrial/commercial soils, the concentrations of fluorene and phenanthrene were reduced most (92.4% and 88.6%, respectively) while pyrene and chrysene were the most resistant to decomposition (24% and 30.9%, respectively). The total PAH concentration (based on analysis for the 16 isomers listed as priority PAHs by the United States EPA) was reduced from 1485 mg/kg to 985 mg/kg, representing a 38.2% reduction.

The results herein reported, although preliminary in nature, indicate that in-situ bioremediation of wood-treatment soils containing chlorinated phenols can be enhanced by application of organic soil amendments either alone or in combination with bacterial inoculation. Two of the in-situ treatments reduced soil PCP concentrations to below CCME guidelines for industrial/commercial soils. Rapid on-site biodegradation of chlorinated phenols and PAHs in highly contaminated, excavated soil was also observed.

Figure 1. Influence of pure culture bacterial inoculation and organic soil amendment on biodegradation of PCP[1] in wood treatment soil.



1. Initial PCP concentration of 1002 mg/kg

Figure 2. Influence of organic soil amendments on phase partitioning of added ^{14}C-PCP.

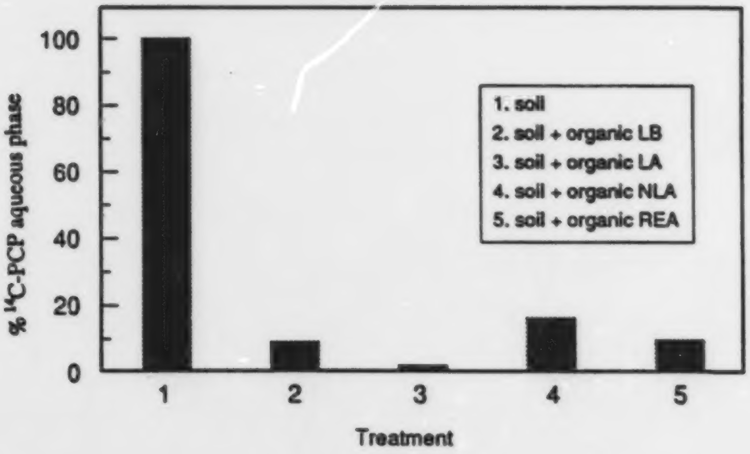


Figure 3a. Biodegradation of PAHs in industrial wood treatment soil.

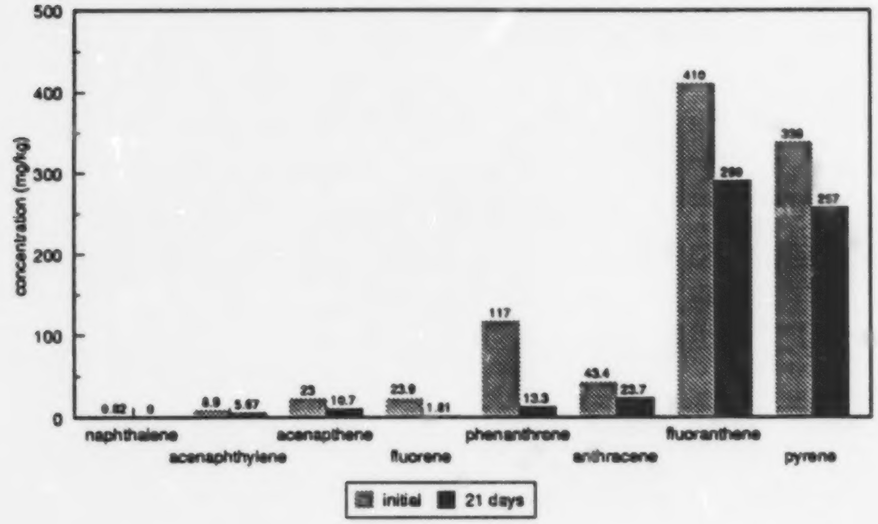


Figure 3b. Biodegradation of PAHs in industrial wood treatment soil.

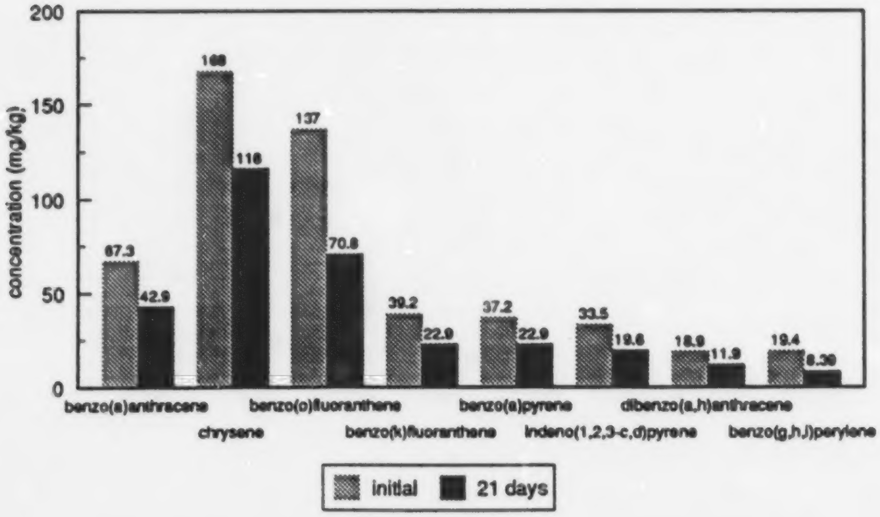


Table 1. Influence of organic amendment technology[1] on Microtox® toxicity[2] of soil leachates[3].

Sample	5 Minute EC_{50}	15 Minute EC_{50}
Control	0.49	0.34
Control	0.32	0.20
NLA	44	41
NLA	44	38

1. Organic amendment NLA added at 5% w/w.
2. % soil leachate in test solution that produces a 50% toxicity response.
3. 2.0 g soil in 25 mL 0.01 M $CaCl_2$. Centrifuged at 2200 x g for 20 minutes.

Table 2. Preliminary data[1] on in-situ biodegradation of pentachlorophenol in soil.

Treatment	Sampling Zone (cm)	Pentachlorophenol Concentration (mg/kg)			
		Pre-treatment		First post-treatment sampling (approx. 11 weeks)	
control	0-15	2.4	Adjusted[2] mean [PCP] = 2.3	1.9	Adjusted mean [PCP] = 2.2
	15-30	3.6		0.97	
	30-60	1.5		2.9	
tillage + inoculation	0-15	51	Adjusted mean [PCP] = 46	6.6	Adjusted mean [PCP] = 6.9
	15-30	21		4.6	
	30-60	55		8.0	
tillage + NLA	0-15	10	Adjusted mean [PCP] = 26	4.5	Adjusted mean [PCP] = 4.4
	15-30	5.0		2.5	
	30-60	45		5.31	
tillage + inoculation + NLA	0-15	1.0	Adjusted mean [PCP] = 21	4.5	Adjusted mean [PCP] = 3.8
	15-30	28		3.9	
	30-60	28		3.4	

1. Values have been corrected for extraction efficiency (87.1%).
2. Mean PCP concentration adjusted for mass of soil in each sampling zone.

Table 3. Influence of organic amendment technology on biodegradation of chlorinated phenols in highly contaminated wood-treatment soil (excavated soil, treated on-site)[1].

Compound	Initial Concentration (mg/kg)	21 Day Concentration (mg/kg)	Reduction (%)
2,6-dichlorophenol	0.558	0.168	69.9
2,4-dichloriphenol	0.635	n.d.	100
3,5-dichlorophenol	0.772	n.d.	100
2,3-dichlorophenol	1.09	3.52	****
3,4-dichlorophenol	1.47	n.d.	100
2,4,6-trichlorophenol	0.034	n.d.	100
2,3,6-trichlorophenol	0.707	0.201	71.6
2,3,5-trichlorophenol	0.637	0.592	7.06
2,4,5-trichlorophenol	0.205	0.175	14.6
2,3,4-trichlorophenol	6.21	0.088	98.6
3,4,5-trichlorophenol	1.60	0.255	84.1
2,3,5,6-tetrachlorophenol	1.90	0.887	53.3
2,3,4,6-tetrachlorophenol	7.05	2.33	66.9
2,3,4,5-tetrachlorophenol	3.17	4.67	****
pentachlorophenol	669	336	49.8
TOTAL CHLOROPHENOLS	695	349	49.8

1. Preliminary data from the first post-treatment sampling.

**** Transient increases in some chlorinated phenols may result from accumulation of products of partial decomposition of more highly chlorinated phenols.

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EDUCATION

Bachelor of Science (Honours), Soil Science, University of Guelph, 1985
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AFFILIATIONS

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PROFESSIONAL EXPERIENCE

Mr. Seech has developed expertise in the areas of biodegradation of organic compounds in soil, determination of microbial biomass size and activity in soil, and pure culture bacterial metabolism. He has studied the influence of soil properties and soil management systems on rates of microbial decomposition of organic compounds in soil under both aerobic and anaerobic conditions. He has experience in determining the influence of soil properties on biodegradation, bioavailability and migration of toxic organic chemicals.

Mr. Seech has extensive experience with the use of radiolabelled compounds in aquatic and terrestrial systems. He has studied transport, phase-partitioning, and biodegradation of a variety of toxic organic compounds, including PCBs, chlorophenols and polycyclic aromatic hydrocarbons. His experience includes rapid determination of biodegradability of toxic organics in soils.

Mr. Seech has authored articles published in refereed scientific journals and has been invited to present scientific papers at international conferences.

Mr. Seech is the inventor of patent-pending technology for in-situ bioremediation of soil contaminated with toxic wood preservatives.

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EDUCATION

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Mr. Marvan has been in the environmental engineering field for over twenty five years. He has been involved in applied research and consulting to governmental agencies, municipalities and industry on a wide variety of environmental matters. During this period, he was responsible for the design, direction and supervision of more than one hundred pollution control projects.

Mr. Marvan is responsible for the performance of the Dearborn laboratories and Environmental Consulting Group.

Mr. Marvan's area of expertise is evaluation of process effectiveness under a wide range of operating conditions, process selection and conceptual design based on custom-tailored evaluations.

He has managed projects which studied the influence of soil properties on binding and transport of aromatic hydrocarbons including dioxins, PCBs and chlorophenols. He has developed expertise in interpreting the influence of matrix variables on migration of organic compounds and the use of solid-phase soil amendments to retard leaching of soluble aromatics in soil.

Mr. Marvan's experience includes studies on biological decomposition of PCBs in industrially contaminated soils and bioremediation of wood-treatment soils. He has also managed several projects that studied biological treatment of industrial wastes.

- 10.0 -

IN SITU BIOREMEDIATION OF SOILS IN A NORTHERN ENVIRONMENT CONTAMINATED WITH FUEL OIL

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ABSTRACT

A site in Whitehorse at which a heating oil spill occurred was deemed a Class A site under the CCME Guidelines, requiring remediation of approximately 300 - 350 m^3 of contaminated soils in the vadose zone. The remediation objectives were to reduce TEH concentrations, which were as high as 30,000 mg/kg, to less than 150 mg/kg. Because excavation and treatment of the contaminated soil was impractical, in situ bioremediation and bioventing was considered the only viable alternative.

Bench scale tests were conducted to identify the optimal bioremediation technology. A series of passive air injection and a withdrawal well were installed to ventilate the contaminated soil mass. A nutrient application gallery was constructed to ensure uniform nutrient loading. A surface barrier was also constructed over the treatment area to prevent short circuiting of air. A single application of nutrient mixed with heated water was made in July, 1991, followed by an application of heated water only in September 1991. The site was monitored by thermistors, suction lysimeters and periodic analysis of vented soil gases.

A limited drilling and sampling program undertaken in October, 1991, indicates that significant remediation of soil hydrocarbons has been achieved, with an average reduction in hydrocarbon concentrations exceeding 85%, and hydrocarbon levels in less contaminated zones reduced to levels below detection. Site closure is anticipated following a further treatment period in the summer of 1992. Based on the results to date, in situ bioremediation appears to be a viable technology for northern environments.

INTRODUCTION

In situ bioremediation of hydrocarbon spills in northern climates has traditionally been considered impractical, due to low ambient temperatures, short treatment seasons and lack of significant in situ microbial populations. However, recent studies and remediation programs have shown that in situ bioremediation can be a successful treatment approach in northern environments. This paper describes the application of an in situ bioremediation technique to remediate soils in the vadose zone contaminated with heating oil from a leaking underground fuel tank at the Department of National Defense (DND) Cadet Camp in Whitehorse, Yukon.

The DND Cadet Camp is located at the southern end of the City of Whitehorse. The camp facilities, including the fuel storage tank, were constructed in 1974. Evidence of improperly-installed fuel supply lines indicates that fuel had been leaking from the tank from the time of installation until its removal in 1991.

The DND Camp is situated on a sand and gravel terrace adjacent to Wolf Creek, a salmon-bearing stream. The site is relatively flat-lying, broken only by a 3 m bench running subparallel to the creek on which the camp buildings are constructed, as depicted in Figure 1. Due to the proximity of the spill to the salmon-bearing stream, the site was classified as Class A site, in accordance with CCREM guidelines (CCREM, 1989). Class A classification represents the highest sensitivity for potential impact.

The climate of the southern Yukon is sub-arctic, characterized by semi-arid conditions, with total annual precipitation of less than 30 cm, and an average of 45 frost-free days per year. The average monthly temperatures for January and July are -21.8°C and 13.9°C, respectively, and the average annual temperature is -1.4°C.

DRILLING PROGRAMS

Drilling was undertaken in two phases; Phase I drilling defined the site stratigraphy and the existence and extent of subsurface contamination, and Phase II drilling focused on installation of the soil treatment and monitoring instrumentation, following definition of the contaminant plume. In the Phase I program, eight exploratory holes were extended with a hollow stem auger through overburden to the water table. Split spoon samples were obtained at regular intervals for field screening and laboratory analysis. Soil samples were screened in the field using headspace techniques with flame-ionization and photo-ionization detectors. Selected samples were sent to an analytical laboratory for benzene, toluene, ethylbenzene and xylene (BTEX) and total extractable hydrocarbon (TEH) analyses.

The Phase II drilling program consisted of installation of sixteen soil treatment wells after the plume had been roughly defined. Six suction lysimeters and one thermistor string were also installed to monitor subsurface conditions during the treatment process. The contaminant plume, treatment wells and instrumentation are presented in Figure 1. Figures 2 and 3 show sections through the contaminated zone.

INVESTIGATIVE RESULTS

The results of the investigative program indicate that overburden soils at the site comprise dense to very dense interbedded silt, sand and gravel units, with cobbles and boulders. The water table is between 7 m and 11 m below ground surface. Groundwater flow is towards the north, roughly paralleling Wolf Creek.

Significantly contaminated soils were encountered in the vicinity of the fuel supply lines to a depth of approximately 4.5 m, and to concentrations of 30,000 ppm TEH. However, the contaminated soils did not extend to the water table, and as the groundwater beneath the site was found to be uncontaminated, only soil remediation was required. The contaminated soil mass as defined by the subsurface investigations has a surface area in plan of approximately 90 m^2 and an estimated volume of 300 to 350 m^3.

Soil moisture contents beneath the site ranged from 2% to 12%. Soil temperatures varied with depth as well as seasonally. As is common in northern climates, soil temperatures were found to decrease with depth in the summer and increase with depth during the winter. During the summer in 1991, near surface temperatures were observed to vary between 0°C and 12°C (Figure 4), while temperature variations at 6.1 m depth varied by 3°C, ranging between 4°C and 7°C.

Discussions were carried out with Environment Canada with regard to remedial objectives. The discussions led to agreement that TEH should be used as the appropriate parameter for measurement of contamination and that 150 mg/kg be the target objective of remediation.

Excavation of the contaminated soil, and treatment off site were initially considered for remediation. However, due to the proximity of adjacent structures and the fact that contamination was found to be as deep as 4.5 m, the associated engineering and construction of supporting structures made this alternative unattractive. As a result, in situ bioremediation was chosen as the most suitable remediation option.

BENCH SCALE TEST RESULTS

Bench scale tests were conducted on native soils from the DND site to evaluate available bioremediation technologies for treatment of the contaminated soils. Uncontaminated soil from the original fuel tank excavation was spiked with known concentrations of #2 heating oil and placed in 1.8 m tall, 100 mm diameter plexiglass columns. The soils were mixed to approximate concentrations of 2,500, 5,000 and 10,000 ppm TEH, and placed in layers from highest concentration at the top of the column to lowest concentration at the bottom of the column. Four remediation technologies were selected for evaluation, following a literature search of available commercial bioremediation technologies, including nutrient solutions and engineered microbes. A fifth column was used as a control, using distilled water as the column treatment solution. Microbial populations in the native soils were not artificially enhanced during bench scale tests. Air was sparged into the columns periodically via sintered rubber tubing, to maintain aerobic conditions. The tests were carried out at room temperature, to facilitate obtaining results by the start of the time window for treatment.

Soil samples were taken from access ports in the columns at regular time intervals and analyzed for TEH, moisture content, microbial population and soil pH. The column elutes were analyzed for TEH and nutrient concentrations. The results indicated that a proprietary nutrient solution supplied by Applied Ecologies Inc. was the most effective remedial agent, with a net decrease in TEH concentrations of 45% after a period of 27 days. The remaining technologies provided TEH reductions between 25% and 43%, the latter associated with a proprietary microbe culture combined with the nutrient. As a result, the proprietary nutrient was selected as the in situ bioremediation agent.

IN SITU TREATMENT SYSTEM

The in situ treatment system consists of a nutrient application gallery, passive air injection and withdrawal well network, and a surface barrier system as well as the site monitoring installations. The nutrient application gallery consists of a series of 40 mm slotted PVC laterals, aligned parallel to each other on approximately 1.5 m centres, and laid horizontally in sand bedding at the ground surface, covering the zone of contamination. The surface barrier consists of a 20 mil plastic membrane covering the contaminated soil footprint, which was installed to provide a surface barrier to air flow to prevent short-circuiting of air through the shallow subsurface.

In the Phase II program, 16 treatment wells were advanced to the base of the contaminated zone, and installed with 50 mm flush-threaded PVC pipe, slotted over the contaminated soil zone, backfilled with cleaned sand through the screened zone. The holes were then grout backfilled to ground surface to provide a secure seal. In addition, six suction lysimeters were installed in three boreholes at depths between 1.7 m and 5.5 m below ground surface. The lysimeter holes were backfilled with a silica powder slurry around the lysimeter and grouted between lysimeters or to ground surface. A thermistor string was installed in a single borehole, with thermistor nodes at depths of 1.8 m, 3.4 m, 4.7 m and 6.1 m. The air withdrawal well (DH-12) was fitted with an air blower pump to mobilize soil gases. The pump is rated for an air flow of 150 cfm.

TREATMENT AND MONITORING PROGRAM

An initial nutrient application was carried out between July 15 and 18, 1991. The nutrient was mixed with heated water (40°C) in a 14,000 ℓ tank to achieve a dilution ratio of 1.5% nutrient to 98.5% water. The mixing ratio was selected to achieve an appropriate nutrient loading to the entire contaminated soil mass while also elevating soil moisture in the contaminated zone to approximately 50% of theoretical field capacity.

Heated water was used to elevate soil temperatures, and thereby enhancing the rate of microbial degradation. A total of about 27,500 ℓ of nutrient solution was mixed and added to the contaminated soil mass over the four day period. The temperature of the nutrient solution ranged between about 20°C and 35°C at the time of application to the soil. A second application of 13,000 ℓ of heated water was made to the treatment area on September 12, 1991, to re-establish optimal soil moisture conditions.

Soil venting/aeration began operation in mid June 1991, to pre-aerate the soil prior to nutrient application and continued until October, 1991. Manometer readings taken on the air injection wells indicated the radius of influence of the air withdrawal well incorporated the entire contaminated soil mass. Soil venting was continued through the treatment period, and periodically monitored for O_2 and CO_2 content in the exhaust stream. Oxygen levels temporarily decreased and carbon dioxide levels increased during the treatment period, indicating increased levels of microbial activity.

The lysimeter results were used to monitor downward infiltration of nutrients following application, as well as levels of microbial activity in the soil mass, through analysis of pore waters. Nutrients were observed to penetrate to the base of the zone of contamination, but did not appear in the deepest lysimeter located below the contaminated zone.

Microbial populations in the pore waters were observed to be quite erratic, with no discernable patterns either spatially or temporally. It is concluded that microbial populations in the pore waters are not representative of populations within the soil matrix, where the bioremediation processes occur.

PRELIMINARY RESULTS

A limited soil sampling program was undertaken on October 16, 1991 to establish the reductions in soil hydrocarbon levels achieved during the summer treatment period. Three holes were drilled by solid stem auger methods to depths of 2 to 3 m, and were sampled at 1 m intervals by split spoon for subsequent laboratory TEH and microbial analyses, with locations indicated on Figure 1. A total of 17 samples were taken from the three test holes. The results of the TEH tests are presented in Table 1. Duplicate analyses were carried out on half of the soil samples, to ensure reproducibility of the results. Replicate samples were also sent to an independent laboratory for verification. The data indicates a high level of reproducibility in the analyses.

Table 1 - Summary of Soil TEH Analyses

TEST HOLE #	ESTIMATED PRE-TREATMENT TEH-mg/kg (1990)	POST-TREATMENT TEH mg/kg (1991)	HYDROCARBON REDUCTION (PERCENTAGE)
TH-1(1 m)	22,000	3316	85%
TH-1(2 m)	12,000	4469	64%
TH-2(1 m)	13,000	<50	99+ %
TH-3(1 m)	<50	<50	
TH-3(2 m)	<50	<50	
TH-3(3 m)	5,500	<50	99+ %

FUTURE WORK

Although significant levels of bioremediation have been achieved, additional site treatment is required to reduce the zones of highest soil hydrocarbon concentrations to acceptable levels and to achieve site closure. An additional nutrient application will be made in June of 1992, and soil venting will be continued through the summer treatment period. A final drilling and soil sampling program will be undertaken in the fall of 1992 to verify achievement of remedial objectives.

CONCLUSIONS

Soils adjacent to the DND Cadet Camp has been contaminated with heating oil from an underground storage tank. Approximately 300 m^3 of sands and gravels with silt interbeds have been contaminated, with TEH contaminations of up to 30,000 ppm. The soil contamination extends to a maximum depth of approximately 4.5 m, with no observable contamination of the underlying groundwater.

Use of an in situ bioremediation scheme has resulted in soil hydrocarbon reductions of 80 to 85%, following a 3 month treatment period. Remediation of the soils is attributed both to soil venting and microbial degradation of the hydrocarbons. It is expected that site closure will be achieved following the 1992 summer treatment period. The results of the program indicate that in situ bioremediation is a viable technology for remediation of hydrocarbon contaminated soils in northern environments.

AUTHOR BIOGRAPHICAL SKETCH

Owen P. Quinn, B.A., B.Sc., M.Sc. is a senior hydrogeologist with Klohn Leonoff. Mr. Quinn has undertaken projects in Western Canada, the United States, Sweden, Indonesia and Oman. Currently he is working on a number of contaminated site investigations and remediation projects, including leachate control and treatment at several industrial landfill sites.

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Robert J. Lorimer, P.Eng. is the Manager of Klohn Leonoff's Northern Engineering Division. He is a civil engineer with wide experience on a variety of civil engineering projects in Canada and overseas, including water resources, hydroelectric, and community development projects, marine pipelines, transmission cables and waste management projects. His experience has covered a full range of field and office activities including project management, site investigations, feasibility studies, conceptual and detailed design, estimating, scheduling, construction supervision, contract administration, and engineering research.

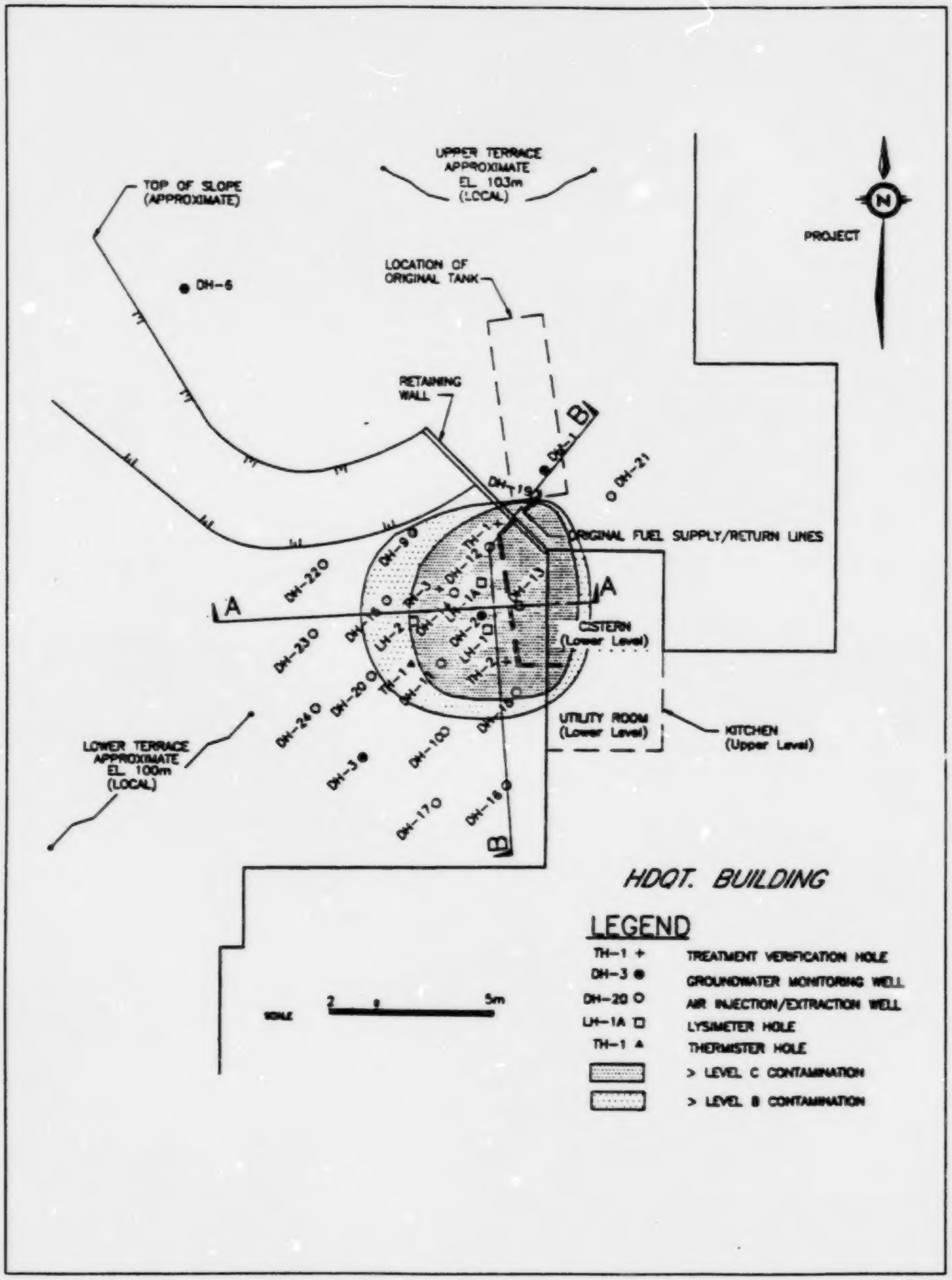
UPPER TERRACE
APPROXIMATE
EL. 103m
(LOCAL)
TOP OF SLOPE
(APPROXIMATE)
PROJECT
N
DH-6
LOCATION OF
ORIGINAL TANK
RETAINING
WALL
B
DH-1
DH-21
DH-19
TH-1
ORIGINAL FUEL SUPPLY/RETURN LINES
DH-9
DH-12
DH-22
A
A
DH-13
LH-1A
DH-11
LH-3
DH-15
LH-2
DH-2
LH-1
CISTERN
(Lower Level)
DH-23
TH-2
TH-1
DH-14
DH-20
DH-24
DH-16
UTILITY ROOM
(Lower Level)
KITCHEN
(Upper Level)
LOWER TERRACE
APPROXIMATE
EL. 100m
(LOCAL)
DH-3
DH-10
DH-17
DH-18
B
HDQT. BUILDING
LEGEND
TH-1 + TREATMENT VERIFICATION HOLE
DH-3 ● GROUNDWATER MONITORING WELL
DH-20 ○ AIR INJECTION/EXTRACTION WELL
LH-1A □ LYSIMETER HOLE
TH-1 ▲ THERMISTER HOLE
▨ > LEVEL C CONTAMINATION
▨ > LEVEL B CONTAMINATION
SCALE
2
0
5m

Figure 1 – Site Plan

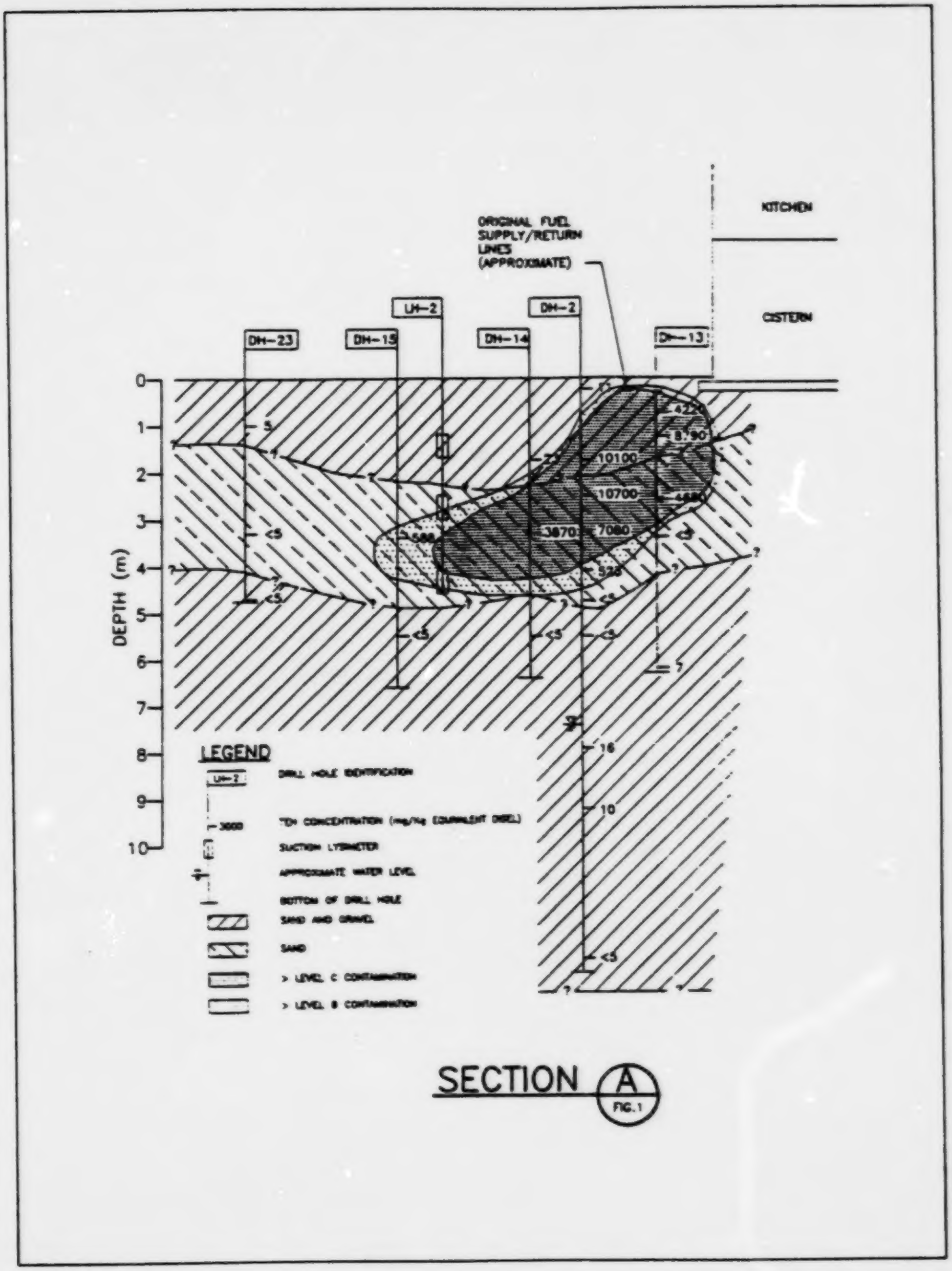
KITCHEN
CISTERN
ORIGINAL FUEL SUPPLY/RETURN LINES (APPROXIMATE)
DH-23
DH-15
LH-2
DH-14
DH-2
DH-13
DEPTH (m)
0
1
2
3
4
5
6
7
8
9
10
5
<5
<5
<5
<5
<5
<5
<5
680
3870
10100
10700
7060
525
16
10
?
LEGEND
LH-2
DRILL HOLE IDENTIFICATION
3000
TEH CONCENTRATION (mg/kg EQUIVALENT DIESEL)
SUCTION LYSIMETER
APPROXIMATE WATER LEVEL
BOTTOM OF DRILL HOLE
SAND AND GRAVEL
SAND
> LEVEL C CONTAMINATION
> LEVEL B CONTAMINATION
SECTION
A
FIG.1

Figure 2 – Section A–A

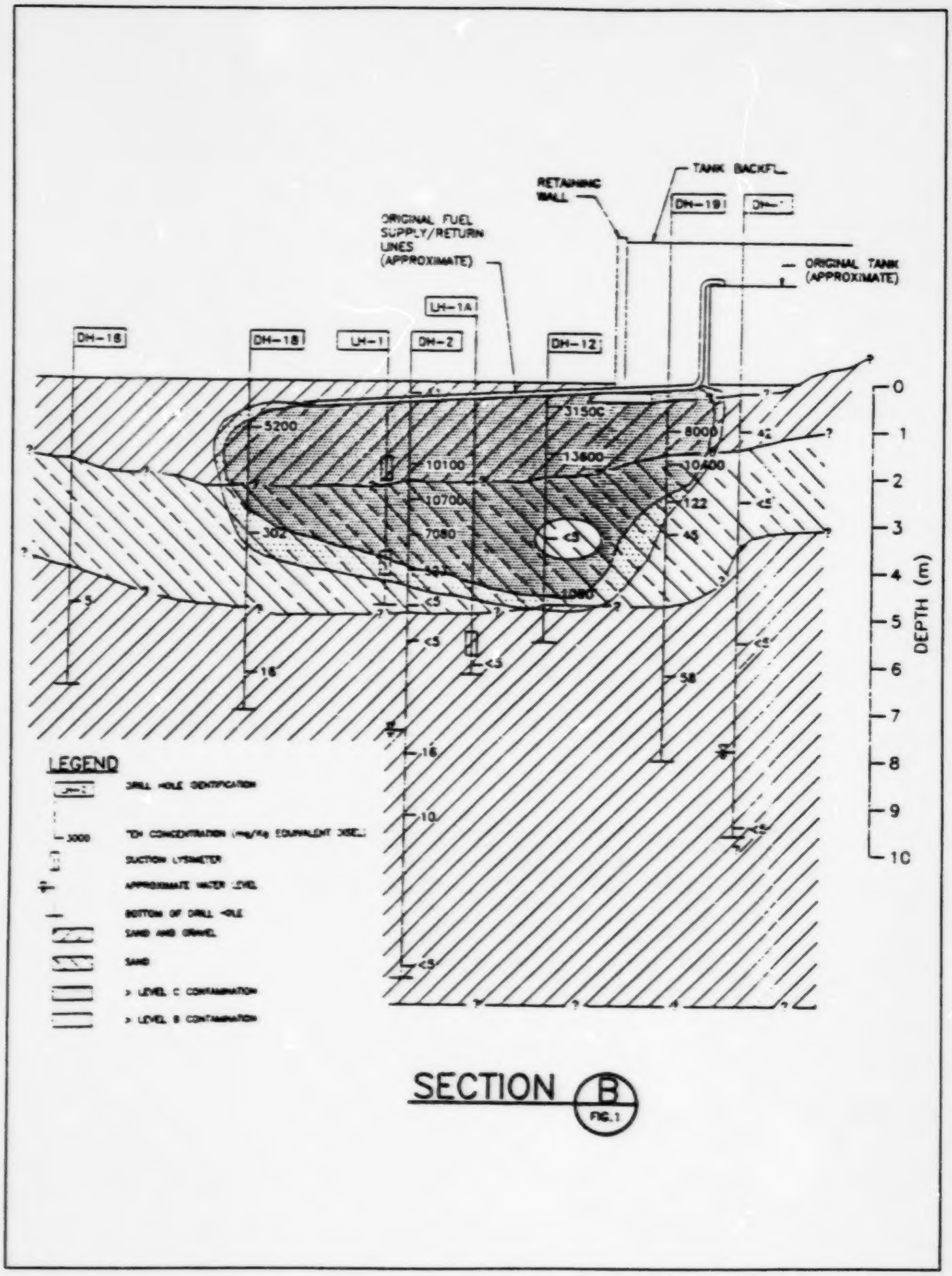
TANK BACKFILL
RETAINING WALL
DH-19
DH-
ORIGINAL FUEL SUPPLY/RETURN LINES (APPROXIMATE)
ORIGINAL TANK (APPROXIMATE)
LH-1A
DH-16
DH-18
LH-1
DH-2
DH-12
5200
3150C
8000
42
13600
10100
10400
10700
122
<5
7080
<5
45
302
327
1080
<5
<5
<5
<5
16
<5
58
16
10
<5
<5
0
1
2
3
4
5
6
7
8
9
10
DEPTH (m)
LEGEND
DRILL HOLE IDENTIFICATION
3000
TPH CONCENTRATION (mg/Kg EQUIVALENT DIESEL)
SUCTION LYSIMETER
APPROXIMATE WATER LEVEL
BOTTOM OF DRILL HOLE
SAND AND GRAVEL
SAND
> LEVEL C CONTAMINATION
> LEVEL B CONTAMINATION
SECTION B
FIG.1

Figure 3 – Section B–B

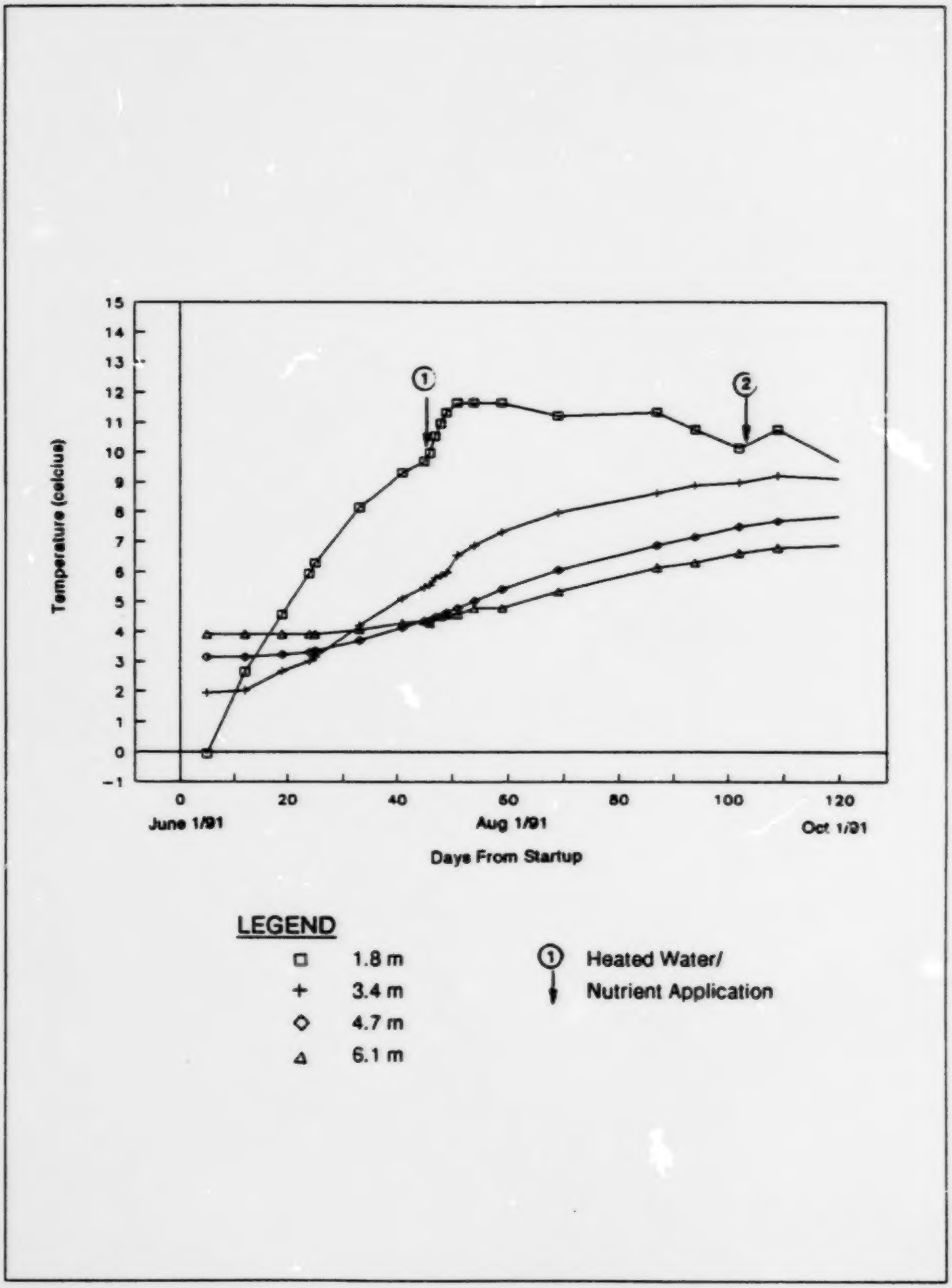

Figure 4 – Ground Temperature Measurements

11.0

A SOLID-PHASE BIO-REACTOR FOR REMEDIATING HYDROCARBON AND SALT CONTAMINATED SOILS AND SLUDGES

by

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A solid-phase Bio-Reactor has been designed to remediate hydrocarbon and salt contaminated soils and sludges. The solid-phase Bio-Reactor is a field facility designed to treat wastes as soil-like material utilizing natural soil processes and to permit the systematic testing of the soil processes affecting remediation. The wastes will be leached using sprinkler irrigation to remove salts and the hydrocarbons will be biodegraded by enhancing the activity of naturally occurring populations of the soil biota. The critical design features of the Bio-Reactor are: (1) forced aeration from beneath the contaminated material; (2) increase in temperature by utilizing waste heat from a gas plant; (3) control of soil water potential; (4) containment and deepwell disposal potential of leachate (i.e., saltwater); and (5) statistical evaluation of treatments. To accomplish these objectives, wastes will be formed into stable, soil-like aggregates to permit rapid and effective leaching and bioremediation. Pretreatment of wastes will be limited to only that necessary to form stable aggregates and to insure rapid bioremediation; the volume of material added to wastes will be minimized to reduce cost. Aeration will be controlled by forcing air through the waste or, alternatively, by non-traffic precision tillage. The water potential of the waste will be controlled by irrigation and the exclusion of precipitation. Heat will be supplied through hot water coils installed in the gravel drain under the waste to increase biological activity and sustain that activity for a longer portion of the year than possible without added heat. Laboratory studies are being conducted to develop methods of forming stable aggregates of various wastes and contaminated soils, and on key factors affecting biodegradation.

The Bio-Reactor Project is co-funded by the Alberta Environmental Research Trust (AERT), Environment Canada, the Canadian Petroleum Association (CPA), the National Groundwater and Soil Remediation Program (GASReP), and The Canadian Petroleum Products Institute (CPPI).

1. INTRODUCTION

The solid-phase Bio-Reactor is designed to provide a controlled environment in which chemicals can be leached and hydrocarbons biodegraded from contaminated soil and soil-like wastes. In a solid-phase Bio-Reactor, contaminated materials are aggregated into structural units that are stable during leaching and can be aerated to maintain aerobic biodegradation of hydrocarbons. Temperature, aeration, and water potential are regulated in individual treatment cells to maintain and test the optimum conditions for bioremediation.

2. PROGRESS TO DATE

The Bio-Reactor project was initiated in April 1991. Three contaminated materials were selected for treatment: 1) an agricultural soil contaminated with crude oil (Waste-1); 2) diesel invert mud residues from a well-drilling operation (Waste-2); and 3) a complex flare pit or natural gasplant sludge (Waste-3). Waste-1 was collected from a spill site in central Alberta where crude oil and brine from a broken pipeline had contaminated the surface soil; the spill occurred in the fall of 1990. Waste-1 was transported to a storage area near the Bio-Reactor site soon afterwards. In July 1991, the material was thoroughly mixed as it was placed in a large tank for storage during laboratory studies. Waste-1 will be amended, aggregated, and placed in the Bio-Reactor for leaching and bioremediation in the spring of 1992.

Komex Consulting of Calgary was hired to design and manage the construction of the Bio-Reactor. The design (Figure 1) underwent several revisions to optimize the control of temperature, leaching, water potential, tillage, loading and unloading of the cells, and protection of the material from precipitation and excessive evaporation. The Gulf Canada Resources Nevis gas plant site was selected for construction of the facility. Construction began in August and was completed in October 1991. Utilities (Figure 2) for the Bio-Reactor will be connected and supplied by Gulf in the spring of 1992.

The hydrocarbons in Waste-1 have been analyzed by Enviro-Test Laboratories. Several laboratory tests are in progress to optimize the leaching and bioremediation of Waste-1.

3. LABORATORY EXPERIMENTS TO ENHANCE BIODEGRADATION OF CRUDE OIL IN SOIL

Experiments are currently being conducted to establish limiting ranges of key parameters that will drive or inhibit the decomposition process in the field Bio-Reactor. Of primary importance are the effects of salts and the quantitative benefits of removing the salts on decomposition, defining N pools and fluxes in hydrocarbon contaminated soils, the potential benefits of elevating temperatures on decomposition rates, and the necessity of using organic amendments.

The basic technique for evaluating decay rates and patterns is measurement of CO_2 efflux from incubated samples; a method which permits frequent or continuous monitoring of hydrocarbon-mineralization. Direct measurements of hydrocarbon disappearance after incubation using solvent extraction are also being done and the two methodologies will be compared. Methods for determinations of available N in oil and salt-contaminated soils are also being evaluated so these parameters can be measured in the Bio-Reactor and soil tests related to N fertilizer requirements.

An initial experiment was performed to determine the effects of electrical conductivity (EC, NaCl) on the general decomposition of plant material and to test respiration methods. The decomposition of alfalfa leaves was insensitive to high salt concentrations and was substantially reduced only when $EC_{SAT} = 36$ dS m^{-1} (Table 1). Fungal growth could easily be observed in the glass incubation tubes and the genera identified in situ. Although salt did not affect gross respiration when added in moderate amounts, the spectra of fungi changed (bacteria not observed). This also occurred when oil was the added substrate, i.e., decomposition in the early stage is an unspecialized process.

In a second test it was shown that oil mineralization was more sensitive to salt than was alfalfa decay (Table 2). However, it appeared that it would not be essential to leach out all the salts in the Bio-Reactor to obtain acceptable decomposition rates.

A preliminary fertilization experiment showed that use of 10:1 C_{OIL}: N_{FERT} ratio suggested in the literature is not applicable when oil contents are high and soluble fertilizers are used (Table 3). High EC's are probably responsible for the inhibitory effect (Table 4) as the use of a slow release fertilizer resulted in higher mineralization rates than with a soluble N-source. Rates of decomposition were similar whether oil contents of 2% or 6% were used.

Further experiments are in progress to determine volatilization losses, soil moisture effects, and methods to boost mineralization rates after the first rapid phase of decomposition and to identify limiting factors during the second, slower phase of hydrocarbon mineralization.

4. TREATING CRUDE OIL CONTAMINATED SOIL TO ENHANCE LEACHING AND BIOREMIDIATION

Establishing and maintaining an optimum physical and chemical environment is a prerequisite to the microbial degradation of hydrocarbons in contaminated soil. Unfortunately, spills of brine and crude oil cause numerous changes in the soil environment that are deletrious to bioremediation. Brine can cause a chemical imbalance in microorganisms and lead to the dispersion of clay minerals. Brine and oil also affect soil properties important to the maintenance of porosity, the supply of water, and the movement of gases in soil. Brine and oil contaminated soil also frequently has a high water content resulting in the formation of large clods when the soil is tilled; clods formation lowers the rate of oil degradation.

Research is in progress to produce uniformly small, but stable aggregates of brine and oil contaminated soil that can maintain stability during leaching, and provide an optimum water and gaseous environment for bioremediation. Understanding how crude oil affects the soil-water-air phase relationships of contaminated soil was the first step in developing methods to manipulate soil aggregate sizes to enhance leaching and bioremediation. This was necessary because previous research had found that crude oil often caused soil to become water repellent, and made manipulation of soil water content difficult. Research to measure water repellency is nearly complete. Preliminary tests have found that salts can be leached rapidly from saturated samples of aggregated soil if the soils are not water repellent.

Research has been completed to provide a reliable method of testing aggregate stability of oil contaminated soil; water repellency of soil under some conditions has made aggregates difficult to wet or reduced their stability when wet. The optimum water content for mixing oil contaminated soil to form small aggregates has also been determined.

The crude oil contaminated soil being evaluated is the surface 15 to 20 cm of a Black Chernozemic soil from near Erskine, Alberta. The texture of this soil is clay loam (sand, 39%; silt, 27%, and clay, 34%). The Atterberg limits of clean soil collected from near the spill site are a plastic limit of 25.5 percent and a liquid limit of 41.2 percent; these limits suggest that the clay minerals are mostly of the nonexpandable types. The organic matter content of the clean soil is 4.2 percent. The crude oil content of contaminated soil is 6.6 percent, as determined by Dean and Stark. The brine in the crude oil results in contaminated soil having a pH of 7.7 and an electrical conductivity of 26.8 mS/cm. The water content of oil contaminated soil following drainage of excess water is high (between 32 and 36 percent).

Mixing oil contaminated soil at a water content of 36 percent produces clods greater than 4.76 mm in diameter with few aggregates less than 1 mm (Figure 3). Drying contaminated soil produces more aggregates in the 1 to 4.76 mm diameter classes. Continued drying of this soil before mixing, however, produces a soil with numerous aggregates less than 1 mm in diameter. Producing a high percentage of aggregates less than 1 mm in diameter could be detrimental to the effective leaching of salts, and the aeration, either natural or forced, during the bioremediation phase of the treatment.

Mixing crude oil with clean soil at water contents less than 25 percent causes the soil to become water repellent (Figure 4). Once contaminated, drying the soil to decrease the water content by a few percent increases the severity of the water repellency. The contaminated soil is also water repellent at water contents below about 25 percent. Water repellent soil is very difficult to rewet. Water repellency will make maintaining a water potential that is optimum for bioremediation more difficult, particularly when the treatment of contaminated soil includes forced aeration.

Water repellent aggregates particularly the larger sizes are difficult to wet, and appear stable. However, after being thoroughly wetted, aggregate stability of oil contaminated soil is less than that of clean soil (Table 5). Thorough wetting of the aggregates will be necessary to leach salts from the oil contaminated soil prior to bioremediation. Aggregates are expected to be least stable during leaching.

In the next few months, a major area of research is to determine the optimum water content and amendments needed to produce stable aggregates; this work is in progress. Chemical amendments to enhance bioremediation will also be included in the aggregation process. The most promising aggregation treatments will be subjected to leaching tests that simulates leaching by intermittent irrigation. Water retention and gas flux through these amended soils will also be determined.

5. OBJECTIVES FOR 1992/1993

This phase of the project will complete the laboratory studies of aggregation and bioremediation of the three waste materials, and leach and bioremediate the oil contaminated soil (Waste-1) in the Bio-Reactor. Air emissions from Waste-1 will also be monitored. A second Bio-Reactor will be constructed adjacent to the first (Figure 5).

The specific objectives are as follows:

1. To characterize the chemical and physical properties of the hydrocarbon contaminated materials.
2. To develop methods to form wastes into stable, soil-like aggregates that can be leached to remove excess salts and that can be aerated to promote biodegradation of hydrocarbons.

3. To determine cost-effective methods to enhance the bioremediation of hydrocarbons, especially with regards to: 1) soil aggregation; 2) aeration; 3) soil water relations; 4) fertilizer amendments; 5) temperature; and 6) organic amendments.
4. Leach and bioremediate Waste-1 in the Bio-Reactor.
5. Monitor air emissions from Waste-1 while in the Bio-Reactor.
6. Construct a second Bio-Reactor adjacent to the first.
7. Design a precision tillage system for the Bio-Reactor if required.

5.1. CHARACTERIZATION OF WASTE

A detailed analysis of the hydrocarbon composition of the three wastes will be done to determine the quantity of the major fractions, and GC/MS analysis will be used to identify individual components. The analyses will include a scan for volatiles (total aromatic volatiles, and interactable compound scan) and scan for semivolatiles (five fractionations, Dean-Stark/asphaltene, and heavy metal scans).

The analytical protocol for hydrocarbon analyses has been prepared by D. Birkholz (Enviro-Test). The QA/QC program will be carried out by Alberta Research Council.

5.2. AGGREGATING WASTES FOR LEACHING AND AERATION

The procedures used to aggregate Waste-2 and Waste-3 will build on the experience gained in aggregating Waste-1. Procedures for aggregating wastes in the field will be developed as the final phase of these studies.

The methods that we expect to used to aggregate wastes are: 1) to change the chemistry of the pore water and cations on the clay minerals; and 2) to add amendments such as peat, straw, or bonding agents. These processes may be enhanced using natural drying forces to change the stress history of the aggregates. The process of aggregating wastes will be evaluated by measuring aggregate stability, aggregate size distribution, hydraulic conductivity, pore size distribution, and compressibility.

Amendments producing the most stable aggregates will be subjected to partly saturated and saturated tests of leaching to remove soluble residues (salts, and organics). The parameters to be varied during leaching include: 1) amount of water used during the saturated leaching of samples; 2) intermittent applications of water (partly saturated leaching); and 3) addition of chemicals and changing the pH of water to enhance removal of salts or enhance aggregate stability.

5.3. LABORATORY STUDIES OF BIODEGRADATION

Laboratory studies of biodegradation of Waste-2 and Waste-3 are needed prior to placement of these materials in the Bio-Reactors in 1993. These tests will be done on aggregated wastes in order to select the optimum amendments for maintaining aggregation and bioremediation. Each waste is expected to have specific requirements for organic and fertilizer amendments to enhance hydrocarbon degradation. In the laboratory studies, response to the amendment treatments will be measured by monitoring CO2 evolution and hydrocarbon disappearance. Total hydrocarbons will be measured before and after each measurement period.

Tests will also be done to determine the value of adding soil that has undergone bioremediation. The added soil should contain micro-organisms more suited for biodegradation of hydrocarbons.

The Bio-Reactor may be operated at temperatures greater than 30°C during the summer months. At present, it is unknown if hydrocarbons can be mineralized with thermotolerant or thermophilic microorganisms. Tests will be made of enriched cultures to determine if such operation is desirable.

5.4. OPERATION OF FIELD BIO-REACTOR

Waste-1 will be aggregated with amendments in May 1992 and placed in the Bio-Reactor with a planned start date of June 1, 1992. The Bio-Reactor contains nine cells which allows for three treatments with three replications. The initial treatments will emphasize tests of the design of the Bio-Reactor's environmental control system and not the process of amending and aggregating wastes. The most likely combination of treatments is: 1) control; 2) forced aeration; and 3) forced aeration and increased temperature. Different cycles of applying water to leach the waste may also be used to determine the most efficient use of water. All cells will be covered to reduce evaporation and better control water potential in the waste during bioremediation. Soil water potential will be maintained near optimum by irrigation.

A composite sample of Waste-1 will be collected from each cell. The hydrocarbon content will be determined on each composite sample. A thorough characterization will be done on a composite sample obtained from each cell. The individual cells will be instrumented to measure temperature and water potential.

Leaching of Waste-1 will begin immediately following placement in the Bio-Reactor. The irrigation cycle will be based on the results of the laboratory leaching studies; preliminary tests indicate that leaching should only take a few days. The quantity of leachate collected in the storage tank of each cell will be measured and samples for selected replications within each treatment analyzed for cations, nitrate, chloride, and hydrocarbons. Composite soil samples from each cell will be collected on a less frequent basis for soil analyses (electrical conductivity, cations, nitrate, chloride, and hydrocarbons).

Target levels of salts to remain in Waste-1 will be based on the results of the laboratory leaching and bioremediation tests.

The disappearance of hydrocarbons will be measured regularly. A composite sample will be collected from each cell as soon as the material is placed in the Bio-Reactor, at weekly intervals during leaching, and weekly and biweekly intervals during bioremediation. Several tests will be done early in the experiment to determine the number of subsamples needed.

Selected soil samples will also be analyzed for key microbial parameters, including basal respiration (CO2 evolution) and microbial biomass (by substrate-induced respiration). Metabolic response parameters will be used to determine the overall functioning of microbial populations and how treatments affect microbial degradation of hydrocarbons.

Temperature and water potential will be continuously monitored in each cell. Detailed measurements of these properties, oxygen diffusion rates, and air permeability in aerated cells will be made to determine the variability of these parameters in the cells and confirm that the locations in the cell where parameters are continuously monitored are representative of the cell.

Fertilizer will be applied to Waste-1 based on tests of extractable nitrogen and phosphorus in soil samples taken from the Bio-Reactor cells and the results of the laboratory tests of fertilizer application rates. The fertilizer application rates will be validated by periodically measuring the microbial response to fertilizer added to these samples. Correlation of fertilizer stimulated CO2 production with extractable nitrogen and phosphorus levels will be used to validate the laboratory tests.

5.5. AIR EMISSIONS

Air emissions from Waste-1 will be measured to quantify the volatilization of hydrocarbons and determine how the concentration of these compounds change over time. The substances in emissions will be measured in three analyses: 1) carbon dioxide; 2) C1 to C5 hydrocarbons; and 3) C5 to C20 hydrocarbons. The analyses reflect differences in the analytical procedures used to measure each group of hydrocarbons.

Emissions will be collected in a flux chamber of common design that is randomly placed on the surface of the waste. Chambers will be portable so that they can be removed and not interfere with irrigation and other operations of the Bio-Reactor. Sampling will begin immediately after Waste-1 is placed in the cells. Air samples will be collected at time 0, 1, 3, 6, 10, and 14 days, and weekly or biweekly thereafter. A sample will be taken from one replication of each treatment. These data will be used to construct the decay curve for emissions from each treatment. The mass per area of selected substances emitted over the duration of the field trial will be estimated for each treatment.

5.6. CONSTRUCTION OF SECOND BIO-REACTOR

Assuming that the results from the first field trials are positive, a second Bio-Reactor with nine cells will be constructed adjacent to the first. The second Bio-Reactor will allow two wastes to be treated simultaneously, or allow more treatments to be compared at one time. The design will be similar to the first, but will incorporate changes identified during testing and operation of the first Bio-Reactor. It is highly probable that the second Bio-Reactor will be winterized to allow year round operation.

5.7. PRECISION TILLAGE SYSTEM

A precision tillage system using a rototiller will eliminate the compaction of waste by wheel traffic and allow a high level of control over the depth at which the waste can be tilled. A conceptual plan for a precision tillage system for the Bio-Reactor has been formulated. If the first round of field trials indicates that tillage is required, a design for the tillage system and how it can most efficiently be used in the operation of the Bio-Reactor will be developed.

6. CONCLUSIONS

The Bio-Reactor allows the rigorous testing of a wide range of salt and hydrocarbon contaminated wastes that are processed as soil-like material and subjected to leaching and bioremediation in a controlled environment. Several combinations of amendments to enhance leaching and bioremediation are being evaluated in the laboratory, and only the most promising treatments will be tested in the Bio-Reactor. These experiments will determine the optimum field conditions for using a solid-phase Bio-Reactor to remove salts and hydrocarbons from wastes, the design parameters for constructing larger facilities and the cost and time required for treating specific wastes.

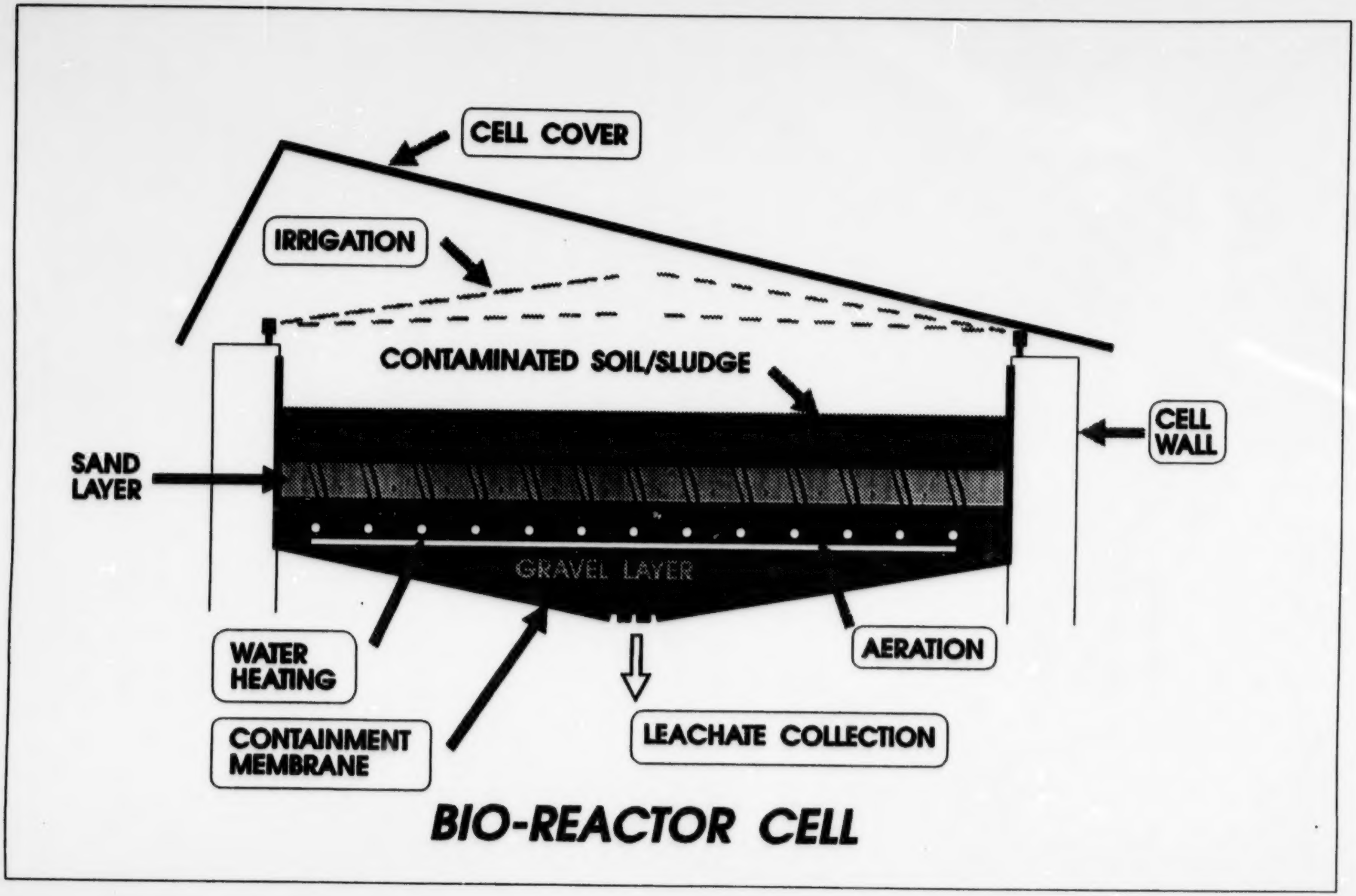

CELL COVER
IRRIGATION
CONTAMINATED SOIL/SLUDGE
SAND LAYER
CELL WALL
GRAVEL LAYER
WATER HEATING
AERATION
CONTAINMENT MEMBRANE
LEACHATE COLLECTION
BIO-REACTOR CELL

Figure 1 Cross Section of a Bio-Reactor Treatment Cell

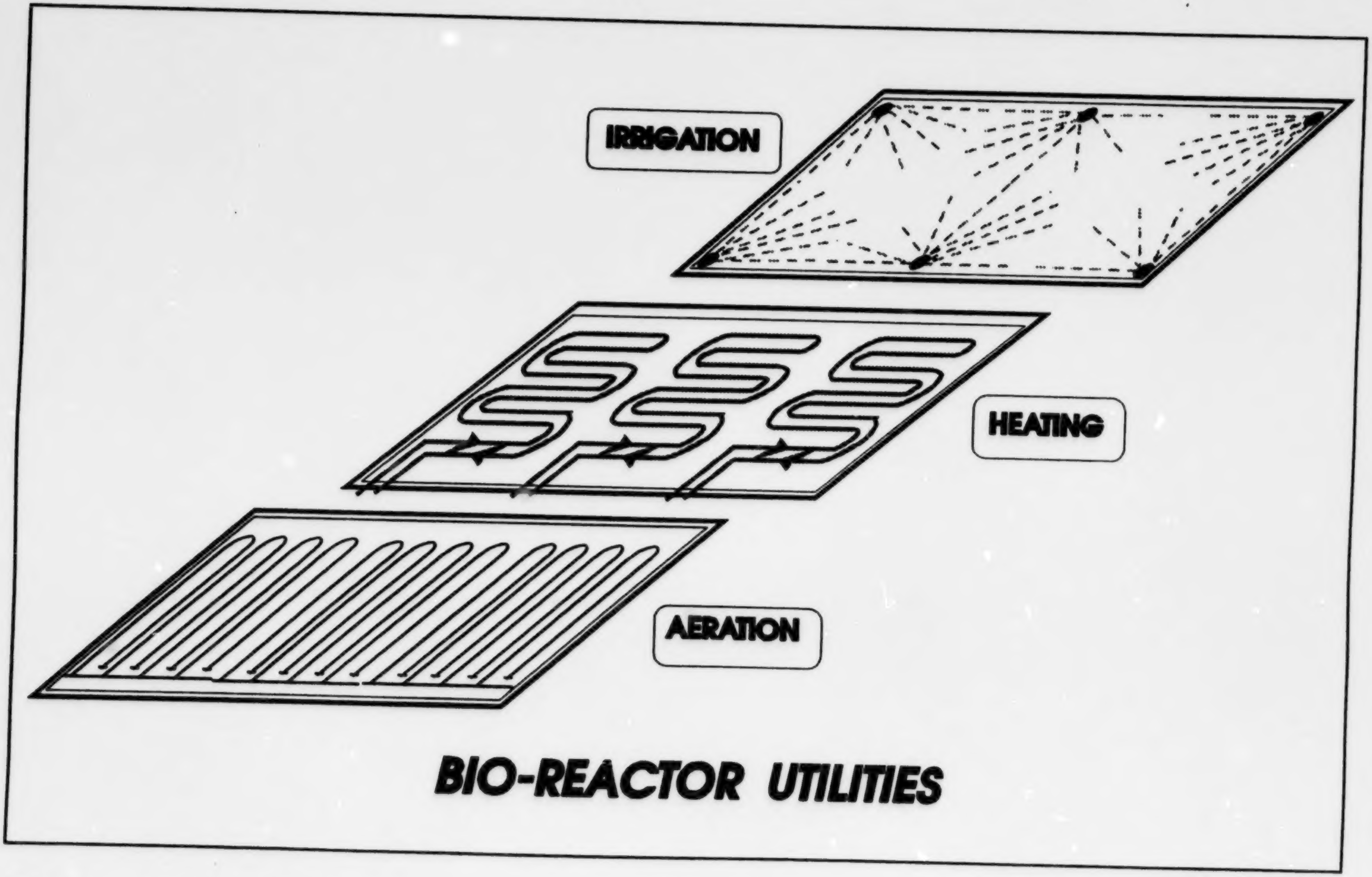

IRRIGATION
HEATING
AERATION
BIO-REACTOR UTILITIES

Figure 2 Bio-Reactor Utilities

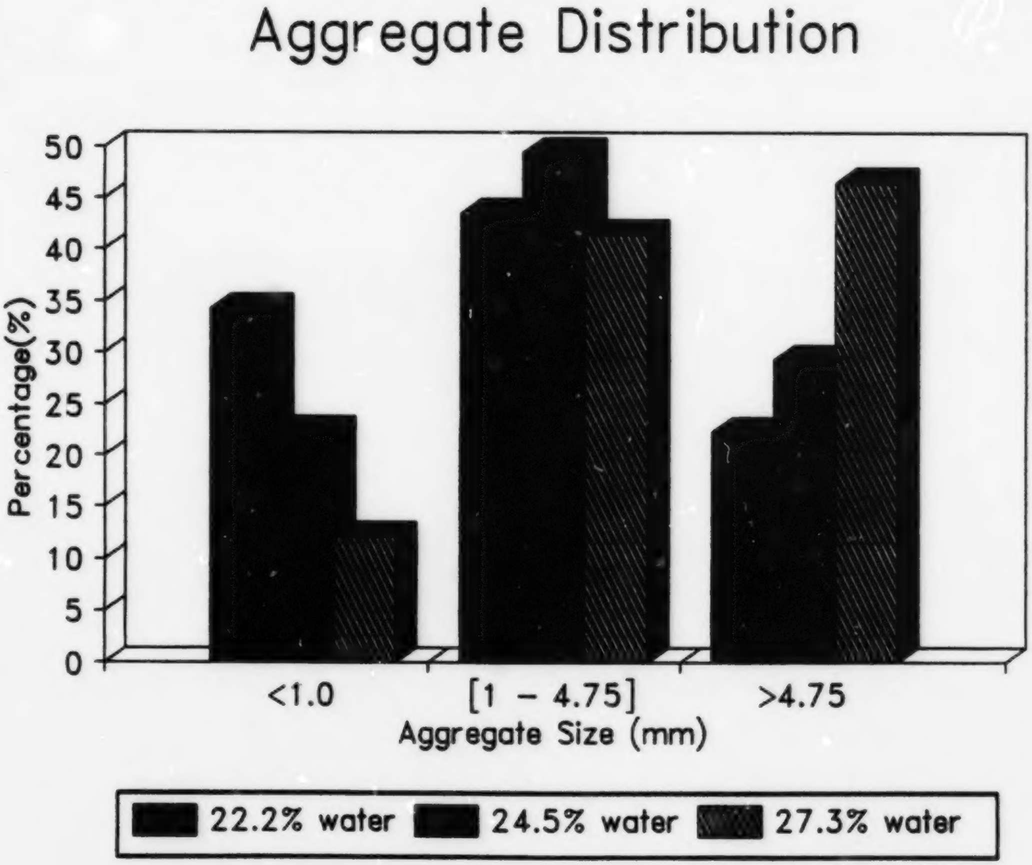


Figure 3 Effect of water content at the time of mixing on distribution of aggregate sizes.

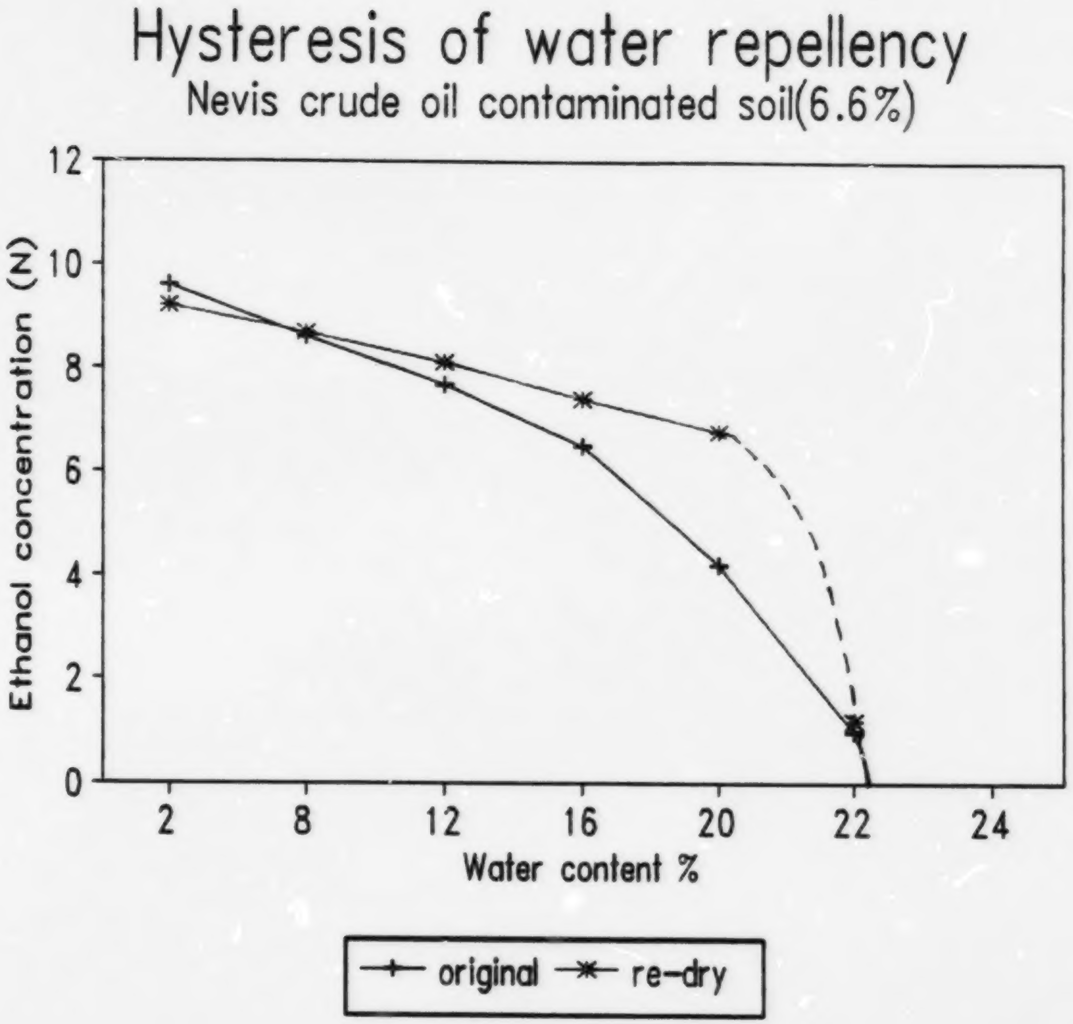
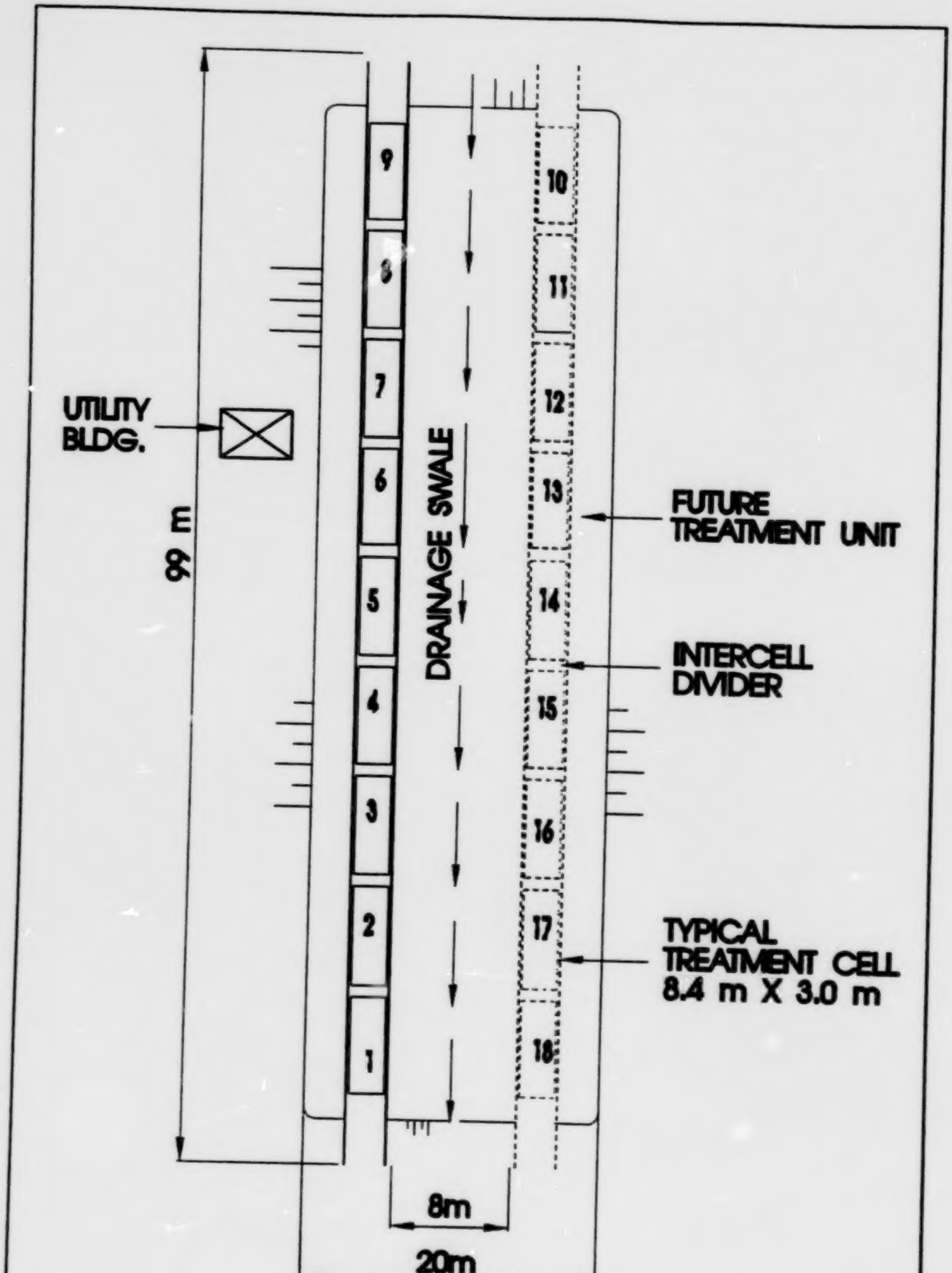


Figure 4 Effect of water content at time of contaminating soil with crude oil on water repellency, and effect of drying wet, oil contaminated soil on water repellency. Water repellency was measured as the concentration of an ethanol in water solution that penetrated soil in 10 sec.


99 m
UTILITY
BLDG.
9
8
7
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2
1
DRAINAGE SWALE
10
11
12
13
14
15
16
17
18
FUTURE
TREATMENT UNIT
INTERCELL
DIVIDER
TYPICAL
TREATMENT CELL
8.4 m X 3.0 m
8m
20m
TREATMENT UNIT

Figure 5   Location of Proposed Second Bio-Reactor

Table 1. Effect of different concentrations of NaCl on the decomposition of alfalfa (2%) added to soil as estimated by CO_2 efflux over a 6 week period.

$EC_{1:2}$ ($dS\ m^{-1}$)	Total CO_2-C evolved ($mg\ g^{-1}$ soil)	Principal fungi observed
1.3	6.2	*Cunninghamella*
1.6	6.3	*Cunninghamella*
2.1	6.3	*Cunninghamella*
2.6	6.3	*Cunninghamella*
3.6	5.6	Unknown
6.2	5.6	Unknown
10.4	5.1	*Penicillium*
18.4	3.0	*Penicillium*

Table 2. Mineralization of crude oil in soil (2%) treated with NaCl and incubated for 8 weeks.

Initial $EC_{1:2}$ dS m^{-1}	NaCl per 100g soil (mmol)	CO_2-C evolved mg g^{-1} soil	Percent of oil evolved as CO_2	Percent reduction in CO_2 efflux
1.6	0	3.0	18	-
3.2	4	2.6	15	13
7.4	16	2.0	12	31
13.2	32	1.0	6	66
22.6	64	0.4	2	87

Table 3. Net loss of CO_2-C from crude oil added to Nevis soil fertilized with $Ca(NO_3)_2$, Osmocote 17-9-13 slow release fertilizer or PK fertilizer over an 8 week incubation period.

Oil (%)	C/N ratio	Fertilizer	CO_2-C evolved			% oil-C evolved as CO_2
			% 0-4 weeks	% 5-8 weeks	Total mg g^{-1} soil	
2	10:1	$Ca(NO_3)_2$	69	31	2.7	16
2	40:1	$Ca(NO_3)_2$	68	32	4.1	25
6	10:1	$Ca(NO_3)_2$	72	28	6.2	12
2	10:1	Slow release	75	25	3.0	18
2	40:1	Slow release	52	48	3.7	22
6	10:1	Slow release	84	16	7.7	15
2	-	PK	60	40	0.9	5
2	-	PK	52	48	1.2	7
6	-	PK	52	48	1.4	3

Table 4. Soil pH and electrical conductivity (EC) of soil containing crude oil and either $Ca(NO_3)_2$ or a slow release fertilizer.

Oil (%)	C_{OIL}/N_{FERT}	Fertilizer	Weeks Incubation 0	8	0	8
			pH_{H2O}		EC ($dS\ m^{-1}$)	
2	10:1	$Ca(NO_3)_2$	6.5	6.7	4.0	3.5
2	40:1	$Ca(NO_3)_2$	6.8	6.7	1.5	1.0
6	10:1	$Ca(NO_3)_2$	6.1	6.6	10.1	9.0
2	10:1	slow release	6.9	6.6	0.4	2.3
2	40:1	slow release	6.9	6.4	0.5	0.8
6	10:1	slow release	6.7	6.2	0.5	5.7

Table 5 Effect of crude oil on the stability of aggregates between 1.2 and 2.0 mm in diameter. Aggregates were all humidified for 2.0 hours and tested with or without soaking for 2.0 hours.

Soil Treatment	Without Soaking	After Soaking
	%	%
Clean soil	69.7	32.7
Contaminated soil	52.6	16.6

12.0

DEMONSTRATION AND EVALUATION OF TREATMENT TECHNOLOGIES FOR THE REMEDIATION OF CONTAMINATED SOILS FROM THE PACIFIC PLACE SITE IN VANCOUVER, BRITISH COLUMBIA

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ABSTRACT

The British Columbia Ministry of Environment, in cooperation with Environment Canada's Demonstration of Site Remediation Technologies (DESRT) Program, has undertaken treatability studies of several treatment technologies. The primary purpose of the studies is to evaluate the effectiveness of technologies in treating soils contaminated with coal tars, heavy metals, chlorophenols, and other organic and inorganic contaminants. The soils, which are categorized as special waste in British Columbia, were collected from the former EXPO 86 site, now known as the Pacific Place site, in Vancouver, British Columbia. The technologies undergoing evaluation include several incineration technologies (rotary kilns and a circulating bed combustor), low temperature thermal extraction (the AOSTRA Taciuk Process and the Chemical Waste Management X*TRAX system), bioremediation, and stabilization/solidification using variations of cement-based and silica-based processes (for soils and treatment residuals containing significant concentrations of leachable inorganics).

This paper presents a summary of the process leading to the treatability study program, describes the technologies tested, and provides a discussion of preliminary results for bioremediation, thermal extraction, and stabilization/fixation technologies.

DEMONSTRATION AND EVALUATION OF TREATMENT TECHNOLOGIES FOR THE REMEDIATION OF CONTAMINATED SOILS FROM THE PACIFIC PLACE SITE IN VANCOUVER, BRITISH COLUMBIA

INTRODUCTION

The British Columbia Ministry of Environment, in cooperation with Environment Canada's Demonstration of Site Remediation Technologies (DESRT) Program, is in the process of evaluating technologies for the remediation of contaminated soils from the Pacific Place site in Vancouver, British Columbia. As part of the evaluation program, treatability studies of several treatment technologies were conducted. The results of those studies are now being received and reviewed.

This paper briefly describes the Pacific Place site, presents a summary of the process leading to the treatability study program, explains the technologies tested, and provides discussions of results from some of the studies. The studies were only recently completed and the reports are still being submitted. Therefore, full review of the reports has not been completed and the discussion of results should be viewed as preliminary.

1.1 THE PACIFIC PLACE SITE

Pacific Place is the redevelopment name for an 82.5 hectare (185 acres) assembly of historical industrial lands lying along the north shore of False Creek in the heart of the City of Vancouver, British Columbia. Most recently, the site gained prominence as the site of the 1986 World's Fair, otherwise known as Expo 86, but over the previous 80 years and longer, it served a wide variety of industrial activities including sawmills, boat building, coal gasification, metal plating, wood preservation, carpet cleaning, railway yards, and fuel storage. In addition, eight refuse dumps were established at various locations over the years and a substantial portion of the foreshore area was recovered with fill material from unknown sources.

The historical uses of the site have resulted in contamination of soils and groundwater in several areas. Much of the contaminated soil will require treatment before site development activities can begin. As a condition of the sale of the lands to private interests, the Province assumed the obligation to deal with the contaminated soil and groundwater existing on the site.

1.2 APPROACH FOR REMEDIATION OF CONTAMINATED SOILS

In late 1989, while field investigation studies were being undertaken to characterize the chemistry, locations, and extent of contamination at the site, the Province decided to identify vendors and technologies that might be appropriate for soil remediation and/or disposal. A Request For Proposal for the remediation of special wastes from the Pacific Place site was issued in January 1990. The proposals received were evaluated using several criteria. Among these were the applicability of proposed technologies to the site, the extent to which the technologies had been developed for full-scale application, and whether the technologies had been demonstrated to be successful in treating soils with similar characteristics.

A short-list of vendors was established as a result of the review process. The next step in the evaluation was then to perform treatability studies of the proposed treatment technologies, using soils from the Pacific Place site.

1.3 OBJECTIVES OF THE TREATABILITY STUDIES

It was realized early in the proposal evaluation process that, with the variety of contaminants and physical characteristics of fill material present on the Pacific Place site, no single technology would be adequate to treat all the special waste soils from the site. Furthermore, in view of the lack of experience by most North American firms in the newly evolving field of soils remediation and the controversial nature of siting remediation facilities, it would be necessary to have a high degree of confidence and assurance in the technologies selected.

Thus, objectives of the treatability studies were to demonstrate the effectiveness of the technologies to remediate various contaminants within a variety of physical soil matrices; demonstrate compliance with environmental standards for process emissions, effluents, and solid residues; allow development of treatment unit cost information; and obtain information potentially useful for application to other contaminated site remediation projects.

1.4 FUNDING

A Federal/Provincial program known as the Development and Demonstration of Contaminated Site Remediation Technologies (DESRT) provides for cost sharing for the development and demonstration of remediation technologies and the remediation of orphaned contaminated sites.

Environment Canada and B.C. Environment entered into an agreement under this program to conduct the Pacific Place treatability studies. Twenty percent of the costs of the treatability study program is borne by the vendors. Under the DESRT cost sharing agreement, approximately 42% of the remaining costs of the treatability studies are being funded by the Federal government, and the Province is assuming the balance.

2.0 SCOPE OF TREATABILITY STUDIES

The technology evaluation and treatability study program includes evaluation and demonstration of incineration, low temperature thermal extraction, bioremediation, and stabilization/ solidification technologies. The thermal and biological treatment technologies are directed at treatment of soils containing primarily organic contaminants. The stabilization/solidification studies are intended to treat soils primarily contaminated with inorganics and inorganics-containing residuals from the thermal or biological treatment processes. The scope of the studies ranged from bench- to full-scale demonstrations.

The technologies being evaluated as part of this treatability study program and their vendors are listed in Figure 1.

Before beginning the studies, all vendors were provided with a general protocol that established testing and performance requirements. Each vendor then prepared a detailed work plan for approval. The protocol required detailed chemical analyses of soil samples, with specified analytical methods, prior to treatment and at the end of the studies, as well as analysis of treatment by-products. Analytical parameters included volatile organic compounds, polycyclic aromatic hydrocarbons, chlorophenols, phenols, metals, cyanide, oil and grease, and total extractable hydrocarbons. In addition, physical analyses were required, including grain size and moisture content.

Brief descriptions and preliminary results of each of the technologies and the scope of the studies are provided in this paper. Particular emphasis is placed on bioremediation and low temperature thermal extraction technologies since they are somewhat innovative for the types of special wastes found on the Pacific Place site.

3.0 COLLECTION AND CHARACTERIZATION OF SOILS TESTED

Soils from the Pacific Place site, characterized as special waste, provided samples for the treatability studies. Several locations and types of soils were selected for excavation, in order to provide a range of the types and concentrations of contaminants for the treatability studies. In addition, a worst case and a more likely case situation were desired.

The selection of sampling locations was determined from data collected during characterization of the Pacific Place site. Analytical data and field logs from borehole and test pit sampling were used to target locations and depths for sample collection.

Samples were collected by digging pits to the desired depths with an excavator. The targeted soils were then mixed in the excavation using the bucket of the excavator. After mixing, samples were screened and were placed into shipping containers, which were included 5 gallon buckets, 45 gallon drums, and 1 cubic metre supersacs (for dry materials).

Four sample types were obtained for demonstration testing. Their general characteristics are presented below and selected analytical information is provided in Tables 1 and 2. The analytical data presented here were obtained from analysis of samples collected during excavation and from split samples returned to the Ministry's third party laboratory by each vendor, prior to beginning treatment.

Sample 1. High PAHs, high oil and grease, high cyanide. This sample location is characterized by the presence of coal tars, believed to be wastes from the former B.C. Electric Railway coal gasification plant located to the east of this sampling location. The average concentration of total PAHs in Sample 1 was 3,375 mg/kg. Oil and grease concentrations ranged from 29,000 to 200,000 mg/kg with average concentrations of 112,000 mg/kg. Total cyanide concentrations in Sample 1 were between 2,900 and 5,000 mg/kg. Cyanide is probably in the form of ferrocyanide complexes most likely from the purifier box associated with the gasification plant. Sample 1 also was notably high in total sulfur (ranging from 1 to 17 percent), which may also be the result of purifier box waste.

Given the high concentrations of contaminants of concern in this sample, it represents a worst case for the purposes of the treatability study.

Sample 2. Moderate PAHs, high metals (especially lead)

This sample was intended to represent a moderate-case organics sample with significant inorganics. Sample 2 also came from an area associated with a coal gasification plant, the former Pintsch Plant near the Roundhouse. Total PAHs in this sample were lower than those targeted and were detected at 42 to 348 mg/kg (averaging 117 mg/kg). Oil and grease concentrations ranged from 4,200 to 15,600 mg/kg. Lead concentrations were between 116 and 5,600 mg/kg in this sample. Zinc was also high, averaging 2,347 mg/kg.

Sample 3. High to moderate levels of chlorophenols

In Sample 3, pentachlorophenol concentrations ranged from 9 to 309 mg/kg (averaging 136 mg/kg) and tetrachlorophenol ranged from 125 to 500 mg/kg (averaging 242 mg/kg). PAHs were also detected in this sample, averaging 260 mg/kg total PAHs. Oil and grease was detected at 8,300 to 23,200 mg/kg.

The treatability study samples that were collected from this location and provided to vendors proved to be problematic. In some cases, chlorophenol levels detected in the samples received by the vendors were insignificant. This was probably due to differences in sample preparation or in the variability in the soil matrix. This also limited the amount of information obtained from the treatability studies regarding the effectiveness of various technologies in treating chlorophenol contaminated soils.

Sample 4. Low organics, high inorganics (especially lead)

Lead concentrations in Sample 4 ranged from 8,000 to 12,500 mg/kg. This sample was also characterized by relatively high concentrations of arsenic (82 to 114 mg/kg) and zinc (3,700 to 5,200 mg/kg). As indicators of organic content, oil and grease concentrations ranged from 145 to 1,000 mg/kg and total PAHs averaged 151 mg/kg. In Special Waste Extraction Procedure testing, lead consistently exceeded the leachate criterion.

4.0 DESCRIPTION OF TECHNOLOGIES, STUDY DESIGN, AND RESULTS

The following sections present brief descriptions of each technology, the procedures used in each treatability study, and preliminary discussions of the study results. Particular emphasis is placed on the low temperature thermal extraction technologies and on bioremediation, because these are viewed as being somewhat innovative for treating the contaminants from the Pacific Place site.

4.1 X*TRAX SYSTEM.

4.1.1 Description of X*TRAX System.

The X*TRAX system, developed by Chemical Waste Management, Inc., is a low temperature thermal separation process that vaporizes or steam strips organic compounds from soils or sludges. The laboratory-scale system consists of an externally heated steel rotary dryer that operates at an average temperature of 850° F. The rotary dryer on the laboratory-scale unit has an inner diameter of 4 inches and a heated section that is 48 inches in length. It can process up to 4 pounds per hour.

A simplified flow diagram of the laboratory-scale system is provided in Figure 2. Soils or sludges are fed into the rotary dryer and heated. Treated solid residues exit the dryer and are collected in a hopper. Nitrogen is used as a carrier gas for the volatilized organics which are transported from the rotary dryer to a gas treatment system.

The gas treatment system includes a spray tower/scrubber, primary and secondary shell-and-tube heat exchangers for condensing the gases, and two activated carbon filters for treating residual organics in the gas stream. In the laboratory-scale unit the nitrogen gas is vented to the atmosphere. In the full-scale X*TRAX system, the nitrogen gas is recycled.

Liquids and particulates (and less volatile organic compounds) from the spray tower are passed through a gravity phase separator and are then filtered to separate out solids. Condensed liquids from the heat exchangers are composited, filtered, and phase separated for further treatment as necessary.

The laboratory-scale unit uses the same components as the full-scale X*TRAX system.

As can be noted from the flow diagram, the X*TRAX system produces several treatment residuals. These are:

- Treated solids from the dryer
- Phase separator water (this is continuously recycled to the spray tower)
- Phase separator filtrate (particulates and some organics)
- Phase separator oil
- Filtrate from condensate
- Condensed water
- Condensed oil (not always produced in lab-scale tests)

4.1.2 Study Design.

Samples 1, 2, and 3 were individually tested in the laboratory-scale X*TRAX system. Target treatment levels for this technology were B.C. Level B Standards for organic compounds in contaminated soils.

Two operating temperatures were tested in these studies: 900° F and 700° F. In all cases, residence time was 85 minutes.

Prior to processing, the samples were screened through a 1/4 inch sieve and then homogenized. The feed was sampled once each hour, beginning and ending at steady state conditions. The feed samples were composited for each temperature condition and later submitted for laboratory analyses. Total feed time averaged 12 hours for each sample type and an average of about 7 kilograms of each soil sample was fed to the system. Feed rate ranged from 8 to 13 grams per minute depending on the sample type.

Treated solids and condensates were collected and weighed every 15 minutes. Solids were composited for each steady state condition and then were subsampled for analytical testing. The condensates from treating each sample were filtered through 25 micron filter paper. The liquid from this process was poured into a separatory funnel from which samples for analysis were taken. The phase separator liquid was also filtered through 25 micron filter paper. The filter cakes and phase separator water products were subjected to chemical and physical analyses. No organic liquid phase products were generated in these studies.

In a departure from standard testing procedures, because of the high cyanide content and low pH of Sample 1, sodium hydroxide was added to the spray tower water and ambient air monitoring for cyanide gases was conducted during the treatment of this material.

4.1.3 Results.

Detailed analysis of the results of the X*TRAX testing has not been completed. However, a preliminary review of the results indicates that the process was very effective in removing organic compounds (at both temperature conditions) from all three of the contaminated soils that were tested.

As expected, the total metals concentrations in the samples did not change significantly as a result of the X*TRAX treatment process. B.C. Special Waste Extraction Procedure (SWEP) testing of the treated soils indicated that the metals present did not exceed SWEP leachate standards.

In Sample 1, the worst-case sample, total PAHs (16) were reduced by 99.93 percent and 99.39 percent in the 900° and 700° F operating conditions, respectively. Table 3 provides summary data on removal efficiencies for selected PAHs in this sample. The concentrations of PAHs (as well as other organic constituents) in the treated soil were well below B.C. Level B and in some cases were below B.C. Level A Standards. Table 4 provides a comparison of the achieved treatment levels and the B.C standards.

Similar PAH and other organic compound removal efficiencies were achieved in Samples 2 and 3.

Pentachlorophenol was reduced by an average of approximately 98 percent, and 2,3,4,6-tetrachlorophenol by an average of approximately 92 percent for all three samples tested. Concentrations of chlorophenols in some of the treated soils appeared to be slightly above B.C. Level B Remediation Standards.

Examination of the analytical testing performed on treatment by-products from this study shows that a significant proportion of the PAHs were removed in the spray tower and were deposited on the phase separator filter cake. A small amount of the total PAHs in the test were also removed from the piping between the dryer exit and the spray tower. PAH concentrations in the condensed water and phase separator water were insignificant. There were insufficient products to allow for the analysis of organic phase liquids.

Total cyanide in the treated soils was reduced from 2,500 mg/kg to 6 mg/kg in the lower temperature run and to less than 0.5 mg/kg in the 900° F run. Some of the cyanide was removed on the phase separator filter cake and from the piping between the rotary dryer and the spray tower.

In summary, while it appears that the X*TRAX system met the target treatment standards for the study, the process also produced waste by-products (such as the phase separator filter cake) that may require additional treatment before disposal.

4.2 AOSTRA TACIUK PROCESS

4.2.1 Description of the AOSTRA Taciuk Processor.

The Taciuk processor is a low temperature thermal extraction technology that separates organics from solids by pyrolysis and distillation. A flow diagram of the Taciuk processor is provided in Figure 3.

The processor consists of a rotary kiln with a preheat zone, operating at about 500° F; a reaction zone, operating at between 700° and 1,200° F; and a combustion zone, operating at 1,000 to 1,500° F. Water vapor and the more volatile organics are extracted in the preheat zone. Oils and heavier organics are removed in the reaction zone. Both the preheat and the reaction zones are maintained in anaerobic conditions to prevent oxidation of the organics.

The combustion zone burns coke from thermal cracking that forms on the solids in the reaction zone. The flue gas from the combustion zone is passed through a baghouse and a wet scrubber. Carbon absorption is sometimes added for final gas scrubbing. Treated solids are discharged from the kiln as tailings. The steam and organics produced in the preheat zone and the organics separated out in the reaction zone are withdrawn under vacuum and are condensed in separate vapor trains.

As can be surmised from examining the process flow diagram, this treatment process produces several treatment by-products. They are shown in Figure 4.

The wastewater produced generally requires treatment before disposal. The oily waste must either be incinerated or used as fuel for the processor.

4.2.2 Study Design.

Both bench- and pilot-scale studies were run for the Taciuk processor. Bench-scale studies were performed in two steps, using a small batch pyrolysis test unit and a batch combustion unit to simulate the operations of the pilot- and full-scale units. Based on the success of the batch-scale testing program, pilot-scale testing in UMATAC's 5 tonne per hour prototype unit was undertaken. Samples 1; 3; a blend of Samples 1, 2, and 4; and a blend of Samples 2 and 4 were tested with the Taciuk processor.

The target treatment levels established for this treatability study were the B.C. Level B Standards for organic compounds.

Table 5 provides a summary of the operating conditions used in the testing program. During each test run, samples of the feed and samples of the treated tailings were collected every 30 minutes. Composite samples of each of these were submitted for analytical testing. Samples of condensates, both water samples and oil samples, were also collected every 30 minutes and analyzed from each run.

Monitoring of stack emissions was also performed during each run to demonstrate that emissions could meet emissions standards and for calculating destruction and removal efficiencies (DRE) and mass balances. Emissions monitoring was typical of the stack monitoring conducted for incinerator test burns.

The data collected from the sampling program were used to calculate destruction and removal efficiencies (using both Alberta Environment and B.C. Environment procedures) and mass balances for hydrocarbons, solids, and water.

Because of the high sulfur content in Sample 1 and the likelihood that the sulfur dioxide emissions would be exceeded, sand was added in a four-to-one ratio to the sample material before processing. Sand was also added to the third and fourth test runs to reduce moisture content. Therefore, the results achieved must be viewed with this in mind.

In addition to the testing with the Taciuk processor itself, bench- and pilot-scale testing of wastewater treatment technologies was also performed as part of this study. Discussion of the water treatment testing program, however, is beyond the scope of this paper.

4.2.3 Results.

Detailed review of the treatability study report has not been completed; however, some preliminary conclusions can be drawn. In general, the Taciuk processor achieved nearly 100 percent removal of organic contaminants from the treated soil (tailings) samples. The concentrations of PAHs in the tailings were all less than detection limits (practical quantitation limits of 0.33 - 0.528 ppm). However, feed concentrations of organics were generally low due to the dilution from the addition of sand before processing. For example, after dilution with sand, the concentration of total PAHs in the Sample 1 run averaged about 46 mg/kg. In the run combining Samples 1, 2, and 4, total PAH concentrations averaged 309 mg/kg.

Table 6 provides summary of PAHs removal for one test run and shows the destruction and removal efficiencies (DRE) calculated according to Alberta Environment procedures, which provide interesting information regarding the mass balance of the treatment process.

During the testing programs sulfur dioxide limits were exceeded in both tests using Sample 1 material. One explanation for this is that the scrubber on the prototype equipment used for the testing program can only achieve 50 to 60 percent sulfur dioxide removal. Particulate limits were slightly exceeded in two test runs. This was reportedly due to damaged bags in the baghouse that were not discovered until testing was completed. Carbon monoxide limits were also exceeded. This may be explained by the low combustion efficiencies attained during the testing program. All metals discharges were well below emissions standards.

In general, all the water products were found to be contaminated with various compounds that would require treatment before discharge. Contaminants present in significant concentrations in one or more of the water samples included oil and grease, phenols, ammonia, hexavalent chromium, aluminum, lead, manganese, and cyanide. Naphthalenes were detected in the sour water and preheat water in the parts per billion range. The scrubber water proved to contain several contaminants in excess of effluent limits including oil and grease, aluminum, arsenic, zinc, manganese, total suspended solids, cyanide, and ammonia.

The oils produced in the tests were also analyzed. In general, the oils contained very low levels of inorganics and low levels of benzene, toluene, ethylbenzene, and xylene (BTEX). Based on preliminary (and incomplete) data from the third party laboratory analyses of oils, significant concentrations of PAHs were found in the oils. These data help support the assumption that most of the organics present in the soils were extracted and were condensed in the oils produced in the process.

Table 7 provides a general idea of the volumes of by-products produced in the Taciuk processor. As an example, approximately 9 tonnes (9,000 kg., wet basis) of Sample 1 mixed with sand produced approximately 696 kilograms of water and 216 kilograms of oil.

Useful information about reduction of chlorophenolic compounds was not generated in this testing program because the concentrations of chlorophenols in the sample received by UMATAC were non-detectable.

4.3 BIOREMEDIATION STUDIES.

4.3.1 Description of Bioremediation Technologies.

Bioremediation of contaminated soil relies on the ability of microorganisms to convert organic compounds to biomass and ultimately to carbon dioxide and water. This process can be enhanced by controlling the pH of the soil, moisture levels and nutrient and oxygen availability.

Two aerobic, "ex situ" bioremediation techniques, solid-phase and slurry phase, were evaluated in these treatability studies.

The most common solid-phase treatment system is known as land-farming. It involves the placement of contaminated soils to a given depth on a treatment pad. Oxygen is introduced by regular tilling of the soil. Moisture and nutrients are sprayed on the surface of the soil and are then tilled into the soil. Land-farming systems generally provide for the collection and recycling of excess precipitation. This treatment method also enhances volatilization of organics from the contaminated soils.

Slurry-phase treatment involves the use of a contained treatment system similar to the activated sludge treatment process in conventional sewage treatment plants. Soils to be treated are mixed with water, nutrients and biomass and are treated in a series of bioreactors. The bioreactors can be above ground tanks or lined lagoons and can be operated as batch or continuous feed systems. Mixing is accomplished by pumping and/or aeration of the slurry. After completion of treatment the slurry is dewatered using evaporation ponds, filters, hydrocyclones, or other drying techniques, alone or in combination.

4.3.2 Study Design.

Three vendors performed bench-scale bioremediation studies of Samples 1, 2 and 3. These studies included two solid-phase (simulated landfarming) and two slurry-phase (bioreactor) studies, as well as specialized mass balance/volatilization experiments. The effects of biostimulation (nutrient-amended) of indigenous microorganisms and bioaugmentation (the addition of specially cultured bacterial populations to the contaminated soils) were also evaluated. In addition to evaluating the reduction of organic contaminants in soils over several weeks, abiotic losses due to volatilization and other non-biologic losses were examined.

The target treatment levels for the bioremediation studies were established either as B.C. Level C Standards for organic compounds in soils or sufficient reduction in organic compounds to allow for disposal of bioremediated soils to a secure landfill. Given the concentrations of PAHs present in the soils and the reported difficulty of biodegrading some PAHs, Level C standards were felt to be the lowest that bioremediation could achieve.

A typical bench-scale solid-phase microcosm is shown in Figure 5. In the solid-phase bench-scale study a small amount of contaminated soil is placed in a shallow pan or bowl. The soil is mixed at specified periods and water and nutrients are added periodically.

A typical bench-scale slurry-phase bioreactor is shown in Figure 6. The bioreactor is supplied with air that is diffused from the bottom of the reactor. An impeller for mechanical mixing is also part of the bioreactor equipment.

There were some variations in the study designs among the three vendors, depending on each vendor's standard operating protocols and the type of treatment originally proposed for full-scale treatment of the Pacific Place soils. The study designs are described in general terms below.

4.3.2.1 Primary Soil Reactors and Slurry Bioreactor Studies.

For both the solid-phase and slurry-phase studies certain operating parameters were common to all studies.

- Soils were homogenized, sampled, and analyzed for chemical and physical parameters (including nutrient analyses) prior to setting up the slurry bioreactors and soil microcosms. All samples were screened to remove oversize material, but the sieve sizes varied between 1 and 5 cm.
- The primary microcosm and bioreactor studies were conducted for 12 to 18 weeks.
- Slurry bioreactors for one study had a capacity of about 75 liters each and were initially set up with a 15 percent solids content. Bioreactors for the other study had a capacity of 20 liters. These bioreactors were set up with a 20 percent solids content. Soil microcosms used 2 to 3 kg. of soil.
- For each sample type, at least one sterile control was set up to evaluate abiotic losses of contaminants. Control soil microcosms and slurry reactors were sterilized with mercuric chloride or formaldehyde.
- Soil and slurry pH was maintained at near neutral conditions. The pH required frequent adjustment for Sample 1, which was unusually low (4 to 6), by the addition of potassium hydroxide, sodium hydroxide, hydrated lime, or unspecified proprietary mixtures.

- Untreated soils were evaluated for nutrient content prior to setting up the studies. Nutrients were added initially to active bioreactors and soil microcosms. Nutrient content was then monitored periodically. The frequency of nutrient amendments to the cultures varied among the vendors from initial amendment only, to weekly amendments.
- All slurry bioreactors and soil microcosms were incubated at between 18 and 25° C. One vendor also conducted a solid-phase study to evaluate the performance of a psychrophilic organism (one that is able to metabolize at lower temperatures than other micro-organisms). They were incubated at 8° C.
- Oxygen was introduced to the solid-phase microcosms by frequent tilling (once or twice a week). Moisture content in the solid-phase studies was monitored by weighing the microcosms. Water was added at least weekly.
- One slurry reactor study utilized commercially purchased bacterial cultures for studying the effects of bioaugmentation. Another vendor utilized several of its own specially developed bacterial cultures in solid-phase studies. Both of these studies also examined biodegradation with indigenous bacteria.

4.3.2.2 Mass Balance/Volatilization Studies.

Three different studies were performed to collect and characterize volatile organic compounds released during bioremediation of the Pacific Place soils. These studies, which were conducted over a nine week period, were performed in triplicate using Samples 1 and 3; a control was also run for each sample type (also in triplicate). Soils were placed in flasks which were connected to positive or negative pressure air pumps. Headspace samples from the flasks were collected in sorbent tubes or impingers and analyzed for organic compounds. Soil samples from the flasks were collected and analyzed at the beginning and conclusion of the studies. There were variations in the experimental approaches and the sorbent media used to entrain the air samples. The experimental approaches are summarized graphically in Figure 7.

4.3.3 Results.

Detailed evaluation of the bioremediation treatability studies has not been completed. However, preliminary review of the results indicates that some degradation of PAHs and chlorophenols did occur in both solid and slurry-phase systems. The extent and rate of degradation varied among the studies and in several cases there were problems with analytical data that may call some results into question. The discussion of the study results focuses on the general trends observed in all three of the studies, comparison of solid-phase and slurry-phase systems, and comparison of biostimulated compared to bioaugmented reactors.

4.3.3.1 Slurry-Phase Studies.

In general, reductions of organic compounds in the slurry-phase studies were reported in both biostimulated bioreactors and bioaugmented reactors. However, the amount of reduction varied between the studies.

Study "A", which depended on indigenous cultures for its 12 week studies, concluded that slurry-phase reduction of organics was somewhat successful. A rapid initial loss of PAHs and chlorophenols was seen in all three samples in the first six weeks of the study. After six weeks, contaminant concentrations appeared to increase in Samples 1 and 3 (PAHs and chlorophenols).

Despite these apparent increases in contaminant concentrations, overall reductions in total PAHs in Sample 1 were about 58 percent. The control bioreactor for this sample had a 37 percent reduction in total PAHs. These results are depicted graphically in Figure 8.

Slurry-phase bioreactors with indigenous microorganisms in Study "A", were significantly more effective at reducing concentrations of the higher ring PAHs than the solid-phase reactors. For example, the average reduction in 4-ring PAHs in Sample 1 after 84 days was 44 percent and of 5-ring PAHs was 74 percent.

Pentachlorophenol concentrations in Study "A", Sample 3 were reduced from approximately 140 mg/kg to 9.6 mg/kg in six weeks. Concentrations then appeared to increase and were at 23 mg/kg by week 12. Overall PCP reduction was about 84 percent. Data from the control reactor were unavailable at the time this report was prepared, but separate mass balance studies estimated that 27 to 28 percent of PCP removals were due to abiotic losses.

Study "B" concluded that only minor biodegradation of organics occurred in either the biostimulated or bioaugmented slurry reactors for all of the sample types. Similar levels of reduction occurred in the control bioreactors for all three sample types. In general, the reductions that were seen occurred within the first three weeks of treatment and in several cases the concentrations of some contaminants appeared to increase between 30 and 60 days and then decrease again at the end of the study period. As an example, total PAH concentrations in the biostimulated sample were reduced from an average of 731 mg/kg to 494 mg/kg after 84 days of treatment; a 32 percent reduction. Concentrations appeared to increase midway through the study, then were reduced. After 98 days of treatment, some additional reduction was achieved. Figure 9 provides a graphic depiction of total PAH reductions for the biostimulated, bioaugmented and control bioslurries.

4.3.3.2 Solid-Phase Studies.

Study "A" concluded that solid-phase biodegradation was not promising. Between 55 and 57 percent reduction in the targeted organic compounds was achieved in soil pan studies using indigenous organisms. Of this, 16 to 52 percent appeared to be due to abiotic losses. Total PAH reductions in Sample 1 are shown in Figure 10. Of the higher ring PAHs, no reduction was seen for fluoranthene. About 28 percent reduction was seen for benzo(a)pyrene; however, the abiotic control showed a reduction of 31 percent. The average reduction in 4-ring PAHs in Sample 1 after 84 days in the soil reactors was 3 percent. No reduction of 5-ring PAHs was seen.

Study "C" evaluated the performance of both indigenous and several specially cultured organisms. The approach used by this vendor was to inoculate the bioaugmented reactors (as well as supplement nutrients) at several times during the study period.

In the Study "C" indigenous soil reactor for Sample 1, there was a reduction of about 28 percent total PAHs over an 18 week period. Much of this loss was represented by reductions in low molecular weight PAHs. Phenanthrene, fluoranthene, and benzo(a)pyrene in this sample were reduced by 8 to 18 percent and by equal amounts in the abiotic control reactors.

Reductions of PAHs in the bioaugmented reactors for this sample varied for each organism. One bioaugmented reactor and the psychrophilic reactor (incubated at 8° C) showed lower reductions in total PAHs than the indigenous reactor. Two bioaugmented reactors performed better than the indigenous reactors, achieving 36 and 69 percent reductions in total PAHs. The latter of these two bioaugmented studies had significantly improved performance in reducing individual PAHs, as well. Comparisons of individual PAH reductions (for Sample 1) in the indigenous reactor and in the best performing bioaugmented reactor are presented in Figures 11, 12, and 13. The best performing bioaugemented reactor also demonstrated reduction of 4-ring and 5-ring PAHs by an average of 55 and 36 percent, respectively.

The soil reactor for the best performing microorganism was not established until 30 days after the other studies and was run for 12 weeks instead of 18. The concentrations for T_0 were apparently not measured for this soil reactor and were assumed to be equal to the initial concentrations for the reactors set up a month earlier. This may not be a valid assumption and may have caused overestimation of the contaminant reduction achieved. In any event, the total PAH concentrations at the end of week 12 were lower than the abiotic control by about 57 percent.

For Sample 3 (chlorophenols), the biostimulated reactor showed a decrease of pentachlorophenol of 65 percent by the week 18. There were no reductions in the abiotic reactor. None of the bioaugmented reactors performed as well as the indigenous reactor.

4.3.3.3 Volatilization/Headspace Sampling Studies.

The volatilization/headspace study results appear to indicate that very little volatilization of PAHs and chlorophenols was occurring. One study reported that less than one percent of removal of these contaminants from the substrate was due to volatilization. Volatilization of volatile organic hydrocarbons was a factor, but the concentrations of these compounds in the soil samples were not significant in the first place.

4.3.4 Summary of Bioremediation Study Results.

All three of the samples appeared to be difficult to bioremediate. Sample 2, with fairly low concentrations of organics was the most amenable to biodegradation. Problems with the low pH of Sample 1 and possible toxicity of the soils in Samples 1 and 3 may be factors that limited the success of the studies.

In Study "A", slurry-phase bioreactors with indigenous microorganisms were significantly more effective at reducing concentrations of the higher ring PAHs than the solid-phase reactors. In study "C", solid-phase study results similar to the Study "A" slurry-phase studies were noted for the best performing bioaugmented reactor.

Despite the reductions observed in the best performing reactors, most of the PAH compounds exceeded B.C. Level C Standards for PAHs. It remains to be determined whether sufficient reduction in organic compounds was achieved to allow for disposal of bioremediated soils to a secure landfill.

4.4 STABILIZATION/SOLIDIFICATION STUDIES.

4.4.1 Description of Technologies.

Stabilization and solidification technologies are intended to reduce the mobility of contaminants through chemical or physical methods, or both. Solidification produces a solid matrix which reduces the surface area across which pollutant transfer can occur and provides a structurally strong matrix that can withstand weathering and bear weight. Stabilization and solidification technologies are often combined.

Those technologies under evaluation in this treatability study program primarily involve the use of Portland cement with proprietary inorganic or organic stabilizers, pozzolanic materials, or aluminosilicates. One technology also employs proprietary polysilicates and calcium reagents. Stabilization/solidification technologies were not proposed as stand alone technologies for the treatment of Pacific Place special waste soils. Rather, they would be used to treat soils contaminated primarily with inorganic contaminants, and for treatment of residuals (such as ash) from other treatment processes in which organic content had been reduced.

4.4.2 Study Design.

The studies were intended to demonstrate the ability of the various stabilization/solidification technologies to successfully immobilize the inorganics of concern at the Pacific Place site. The studies focused on stabilization of inorganics in untreated soils from the site and stabilization of ash produced during incineration of contaminated soils. Bench-scale studies were carried out by six vendors using either Sample 2 or 4 soils or ash produced in laboratory-scale or pilot-scale thermal processes.

The BCE Interim Protocol for Delisting Special Wastes and Residues provided the protocols used to evaluate the effectiveness of the stabilization/solidification processes and to determine if the stabilized materials could be delisted under any of the management scenarios provided in the Protocol. Many of the tests prescribed in this Protocol were originally developed by the Environment Canada Wastewater Technology Centre (WTC) in Burlington, Ontario. A listing of the specific testing protocols used in this program is provided in Table 8.

Performance criteria for each testing protocol have been established for various disposal options. The disposal scenarios include: unrestricted utilization (the most stringent performance standards); approved utilization; sanitary landfill; and monofill landfill.

Prior to treatment, soils and ash were analyzed for total metals and were subjected to the SWEP procedure, the seven day leach test (WTC Method 9), and the sequential chemical extraction test (WTC Method 12). These analytical procedures, as well as the remaining protocols shown in Table 8, were also performed after samples were stabilized. Certain tests were only performed if the stabilization process produced a monolith (such as the dynamic leach test).

In the bench-scale tests the contaminated materials to be stabilized were mixed with the additives and liquids using blenders or electric mixers. The mixtures were then poured into molds as prescribed by the various test protocols and cured for a specified number of days (minimum of 28 days) before testing.

Most study designs used a modified factorial approach to optimize stabilization studies, using several formulations and conducting preliminary screening techniques to evaluate each formulation. The best performing formulations were then used to stabilize samples for testing with the entire suite of protocols.

4.4.3 Results.

Review of the stabilization study reports is in progress, so no discussion of results have been provided in this paper.

4.5 PX*ROX INCINERATOR

Chemical Waste Management's PY*ROX 8200 incineration system consists of a rotary kiln primary combustion chamber and a secondary combustion chamber. Emissions control equipment on the PY*ROX incinerator includes a baghouse for collection of particulates and wet scrubber for acid gas removal.

The PY*ROX has been used in many full-scale applications and has been demonstrated to meet a minimum of 99.99% destruction and removal efficiency (DRE) of hazardous wastes. Because the technology has been well demonstrated, a full-scale test burn was not performed for this treatability study. Instead, the incineration process was modelled using the physical and chemical characteristics of the Pacific Place soil samples as inputs for calculation of feed rates, emission levels, performance efficiencies and ash residue concentrations. In addition, laboratory scale incineration was undertaken to produce ash for determination of leaching characteristics.

As a result of computer modelling, it was concluded that with operating temperatures between 1200 and 1800° F in the primary combustion chamber and greater than 1800° F in the secondary combustion chamber, a DRE in excess of 99.99% could be achieved for all organic contaminants present in the Pacific Place soils.

With respect to metal residues in gaseous emissions, a worst case scenario based on incineration of soil with no BTU heating value, predicted that there may be emissions of manganese and antimony in excess of standards in some of the samples.

4.6 CIRCULATING BED COMBUSTOR

Ogden Environmental Services has proposed the use of its Circulating Bed Combustor (CBC) for the treatment of contaminated soils from the Pacific Place site. The CBC is a variation of the conventional fluidized bed incinerator that uses a high velocity air flow to obtain high turbulence in the combustion zone. The incinerator operates at temperatures ranging from 790 to 980° C. Limestone can be added to the feed to control acid gas.

This technology has been demonstrated to attain DREs in excess of 99.99% when incinerating soils contaminated with PCBs and other organic compounds at various sites in the U.S.. Because the CBC has been satisfactorily demonstrated at full-scale, only bench-scale studies using a spouting bed combustor were performed for this treatability study. The purpose of the bench-scale studies was to secure information related to soil heating values and general combustion information in order to calculate unit treatment cost information. The bench-scale work also produced ash residues for evaluating the need for studying stabilization/solidification techniques.

The spouting bed combustion tests were useful in obtaining information for full-scale application of this technology. No signs of agglomeration or melting of ash were evident at temperatures at which the CBC normally operates.

4.7 AQUA GUARD THERMAL OXIDIZER

The Bennett Remediation Services Aqua-Guard thermal treatment technology consists of a rotary kiln thermal desorber and a high temperature secondary combustion chamber. The emission treatment system includes dual baghouses for capture of particulate matter and a dry scrubber for control of acid gases.

Full-scale test burns were conducted with Samples 1, 2, and 3. The test burns included stack emissions monitoring, and collection of feed and ash samples. Results of the test burns were unavailable at the time this report was prepared.

5.0 SUMMARY AND CONCLUSIONS

Four major categories of treatment technologies were studied to evaluate their effectiveness in treating contaminated soils from the Pacific Place site in Vancouver, British Columbia. These technologies included incineration, low temperature thermal extraction, biological degradation, and stabilization/solidification. Treatability studies were performed by several vendors using contaminated soils from the site. Results of the treatability studies have only recently been received and are currently under review. Therefore, any discussion of results or conclusions presented in this paper should be considered as preliminary.

Initial review of information from the treatability studies indicates that several treatment technologies may have application for the treatment of special waste soils from the Pacific Place site.

The two low temperature thermal extraction technologies that were demonstrated, the X*TRAX and the TACIUK processes, appear to be effective in reducing organic contaminant concentrations in soil. Both of these technologies function as volume reduction techniques, where contaminants are not destroyed, but are separated into other matrices with lower volumes than the original soil volume. Despite the apparent success of the two demonstration tests, there are several concerns remaining to be addressed, including the cost of treatment, scale-up for full-scale treatment, air emissions, and treatment and disposal of treatment byproducts.

Some reduction in the concentration of organic contaminants was demonstrated in both slurry and solid-phase bioremediation systems. None of the studies was successful in reducing the concentrations of all contaminants to achieve B.C. Level C Standards during the 12 to 18 weeks of the study period. A determination of whether the contaminant concentrations were reduced to a sufficient degree to allow for disposal in a secure landfill has not been made.

Stabilization and solidification studies were performed to study their ability to immobilize inorganic contaminants either in untreated soils low in organics, or in ash produced from thermal treatment technologies. This will be one of the first instances where these technologies will be evaluated with the B. C. Interim Protocols for delisting special wastes. Results of the studies are under review and were not far enough along for discussion in this paper.

It is expected that incineration of the contaminated soils will be a viable treatment alternative in terms of its ability to destroy organic contaminants. However, the results of one full-scale test burn have not yet been received, and other reports are under review. Of particular concern is the ability of each incineration technology to meet emissions standards.

Figure 1

TECHNOLOGIES UNDER EVALUATION IN THE PACIFIC PLACE TREATABILITY STUDY

- **PY * ROX INCINERATOR: Chemical Waste Management, Inc.**
- **THERMAL OXIDIZER: Bennett Remediation Services, Ltd.**
- **CIRCULATING BED COMBUSTOR: Ogden Environmental Services**
- **X * TRAX SYSTEM: Chemical Waste Management, Inc.**
- **AOSTRA TACIUK PROCESS: UMATAC Industrial Processes**
- **BIOREMEDIATION:**
  - **Chemical Waste Management, Inc.**
  - **Waste Stream Technology, Inc. (Subsidiary of Sevenson Environmental, Ltd.)**
  - **Remediation Technologies, Inc.**
- **STABILIZATION / SOLIDIFICATION:**
  - **Chem-Security, Ltd.**
  - **Chemical Waste Management, Inc.**
  - **Bennett Remediation Services, Ltd.**
  - **Newalta Corporation**
  - **Chemfix Technologies, Inc.**
  - **Wastech, Inc.**

Figure 2

PROCESS FLOW
LABORATORY X * TRAX UNIT

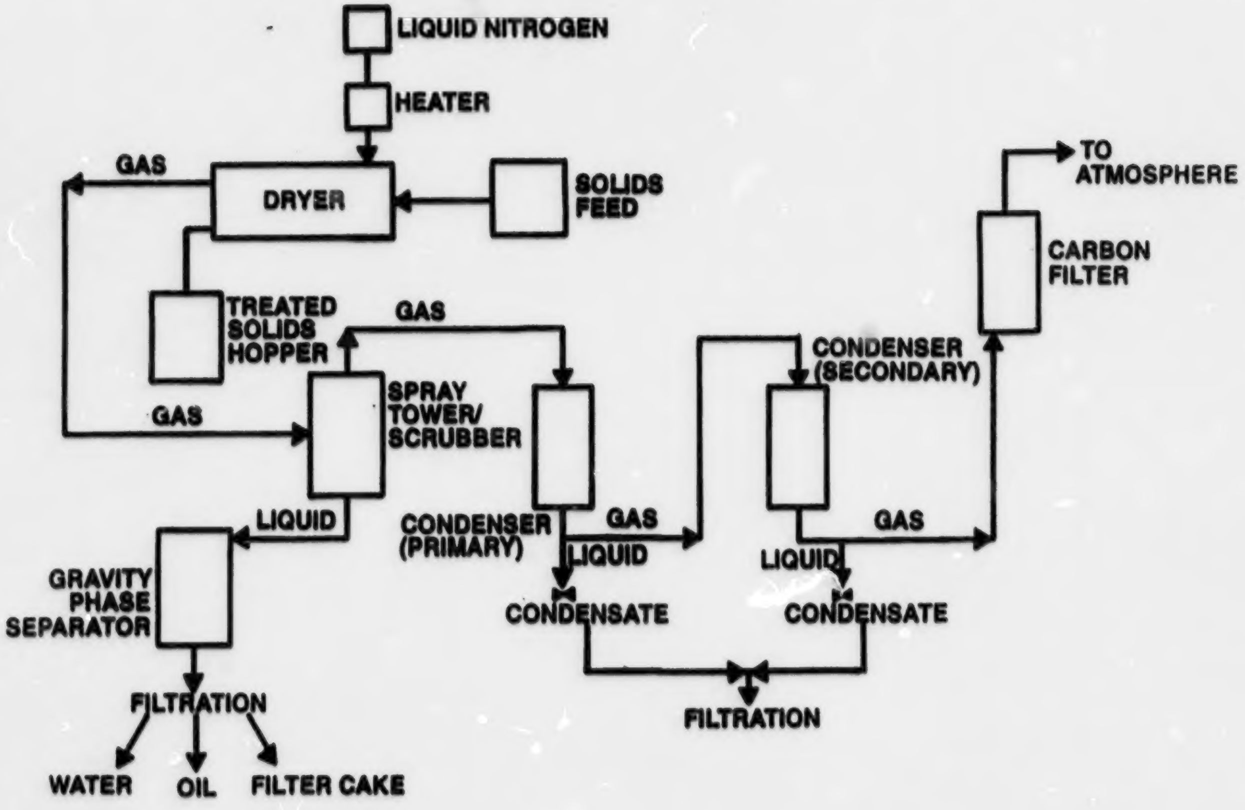

LIQUID NITROGEN
HEATER
GAS
DRYER
SOLIDS FEED
TO ATMOSPHERE
CARBON FILTER
TREATED SOLIDS HOPPER
GAS
CONDENSER (SECONDARY)
GAS
SPRAY TOWER/ SCRUBBER
LIQUID
CONDENSER (PRIMARY)
GAS
LIQUID
LIQUID
GAS
GRAVITY PHASE SEPARATOR
CONDENSATE
CONDENSATE
FILTRATION
FILTRATION
WATER
OIL
FILTER CAKE

Figure 3

AOSTRA TACIUK PROCESS (ATP) FLOW DIAGRAM

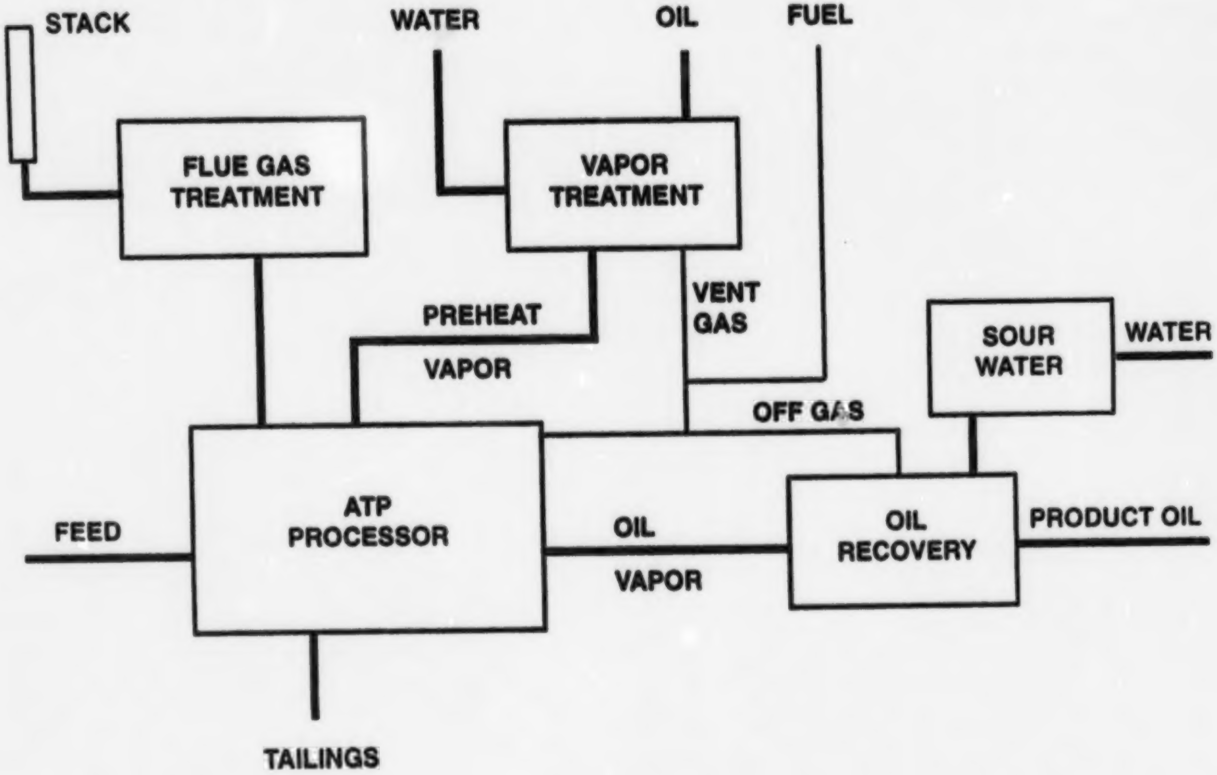

STACK
WATER
OIL
FUEL
FLUE GAS TREATMENT
VAPOR TREATMENT
PREHEAT
VAPOR
VENT GAS
SOUR WATER
WATER
OFF GAS
FEED
ATP PROCESSOR
OIL
VAPOR
OIL RECOVERY
PRODUCT OIL
TAILINGS

Figure 4

TREATMENT BY-PRODUCTS FROM THE TACIUK PROCESSOR

- **Preheat zone - vapour stream**
  Vapour stream:
  - **Water**
  - **Oil**
  - **Gas - recycled to combustion unit**

  Solids stream:
  - **Coked solids (to combustion zone)**

- **Reaction zone**
  Vapour stream:
  - **Cyclone solids**
  - **Bottom soils (removed at 150° - 210° C)**
  - **Heavy oils (removed at 100° - 150° C)**
  - **Light oils (removed in heat exchanger)**
  - **Sour water**
  - **Off gases (flared or recycled to combustion zone)**

- **Combustion zone**
  - **Treated tailings**

  Flue gas stream:
  - **Cyclone fines**
  - **Baghouse fines**
  - **Scrubber water**
  - **Scrubber solids**
  - **Cleaned gas**

Figure 5

TYPICAL BENCH SCALE SOLID PHASE BIOREMEDIATION MICROCOSMS

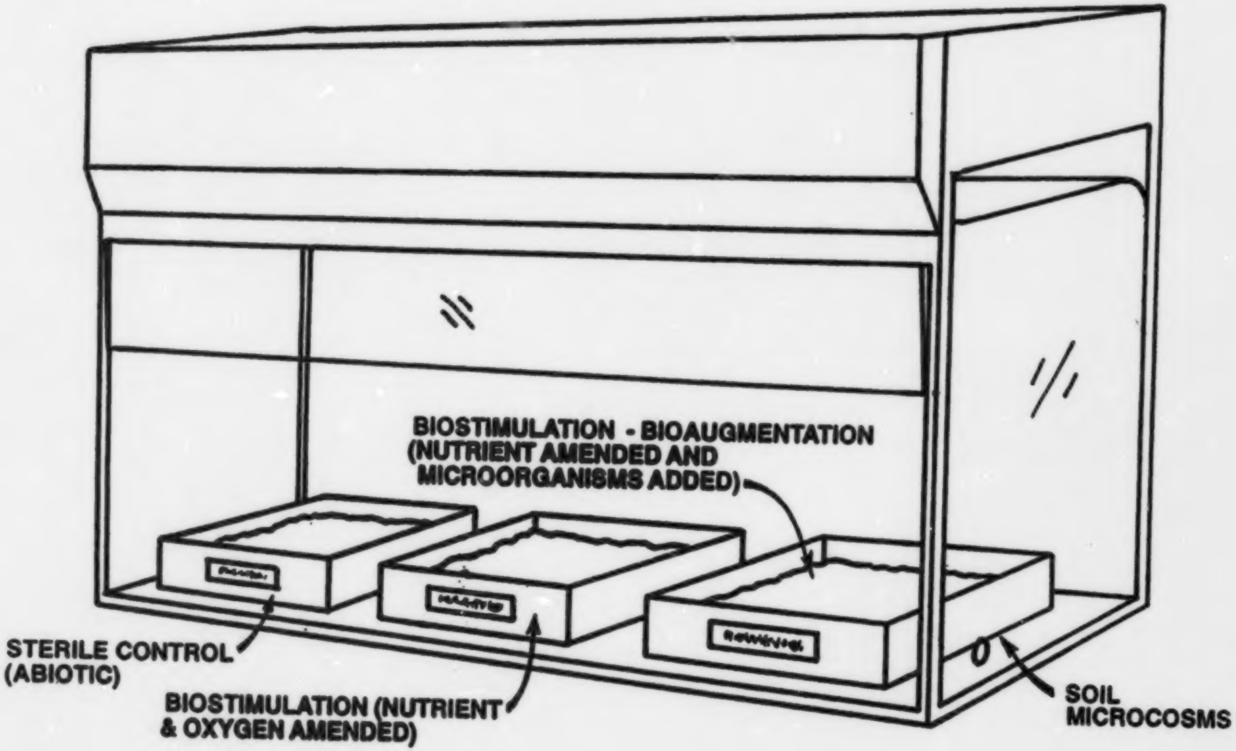

BIOSTIMULATION - BIOAUGMENTATION (NUTRIENT AMENDED AND MICROORGANISMS ADDED)
STERILE CONTROL (ABIOTIC)
BIOSTIMULATION (NUTRIENT & OXYGEN AMENDED)
SOIL MICROCOSMS

Figure 6

TYPICAL BENCH SCALE BIOSLURRY REACTOR

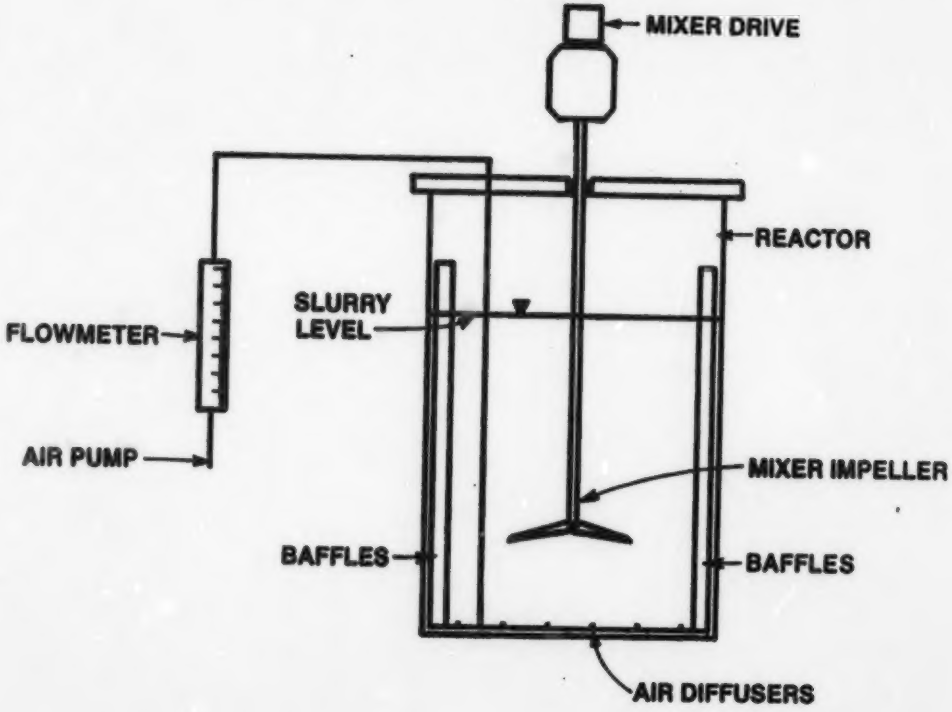

MIXER DRIVE
REACTOR
SLURRY LEVEL
FLOWMETER
AIR PUMP
MIXER IMPELLER
BAFFLES
BAFFLES
AIR DIFFUSERS

Figure 7

TYPICAL BIOREMEDIATION VOLATILIZATION STUDY SCHEMATIC DIAGRAMS

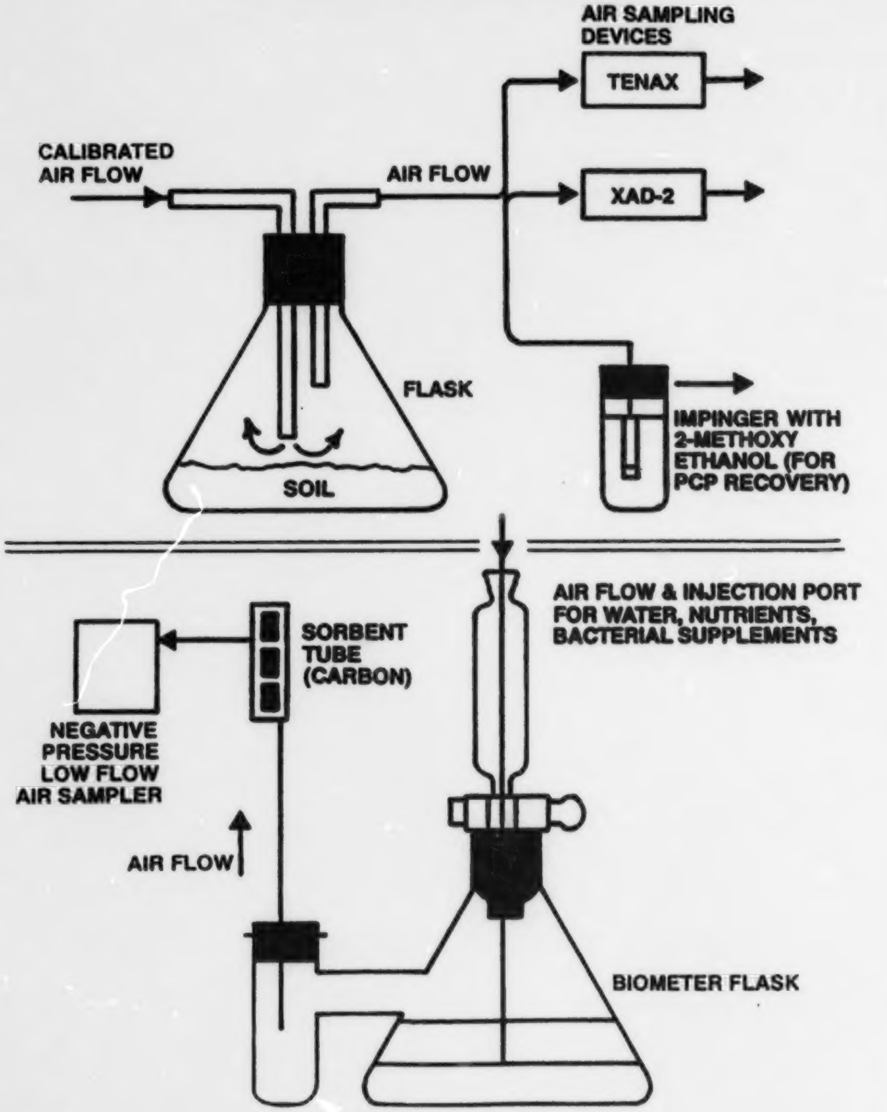
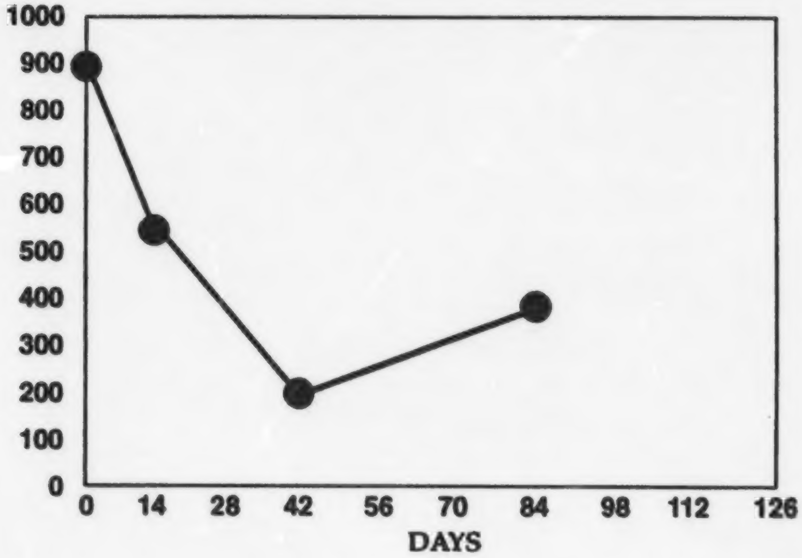

AIR SAMPLING DEVICES
TENAX
XAD-2
CALIBRATED AIR FLOW
AIR FLOW
FLASK
SOIL
IMPINGER WITH 2-METHOXY ETHANOL (FOR PCP RECOVERY)
AIR FLOW & INJECTION PORT FOR WATER, NUTRIENTS, BACTERIAL SUPPLEMENTS
SORBENT TUBE (CARBON)
NEGATIVE PRESSURE LOW FLOW AIR SAMPLER
AIR FLOW
BIOMETER FLASK

Figure 8

STUDY A
BIOSTIMULATED SLURRY BIOREACTOR RESULTS
Total PAH, SAMPLE 1



56% REDUCTION
BC LEVEL C = 200 mg/kg

Figure 9

STUDY B
SLURRY BIOREACTOR RESULTS
Total PAH, SAMPLE 1

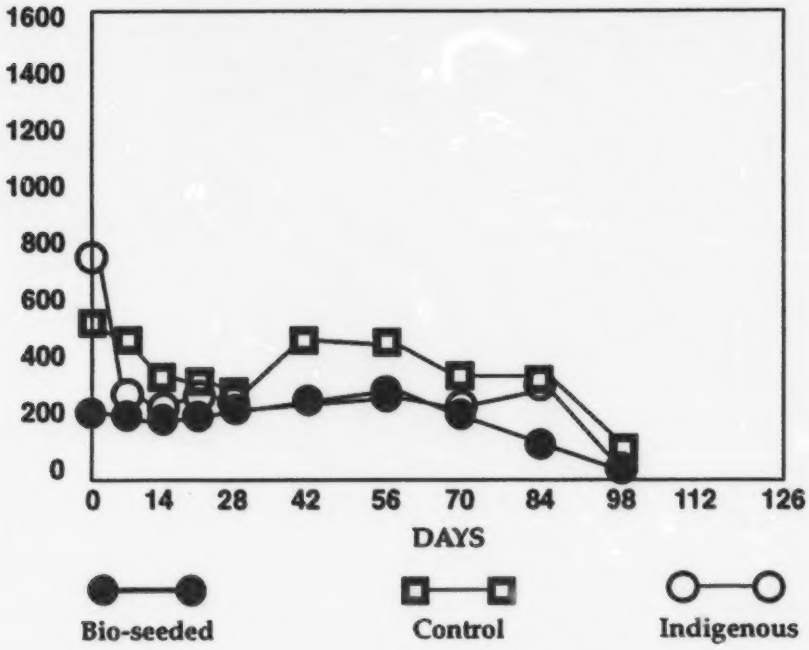
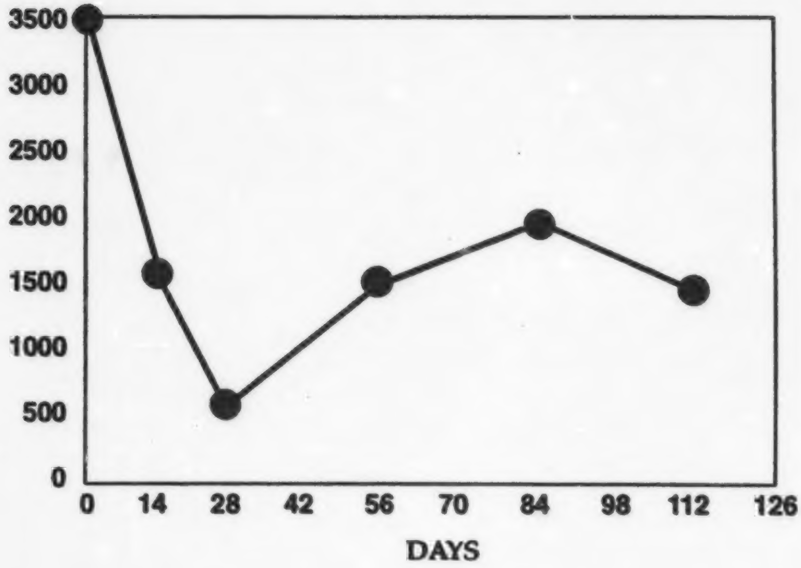


Figure 10

STUDY A
BIOSTIMULATED SOIL
REACTOR RESULTS
Total PAH, SAMPLE 1

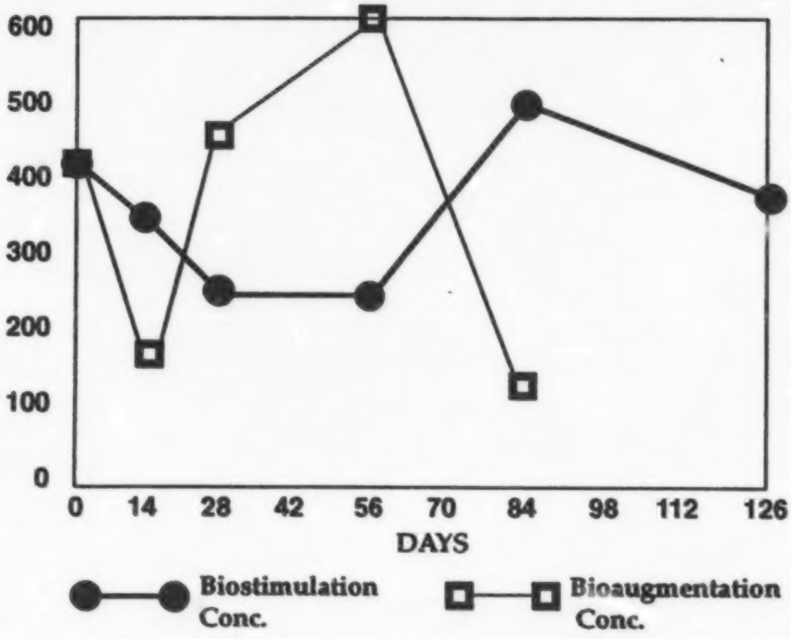


REDUCTION	
BIOSTIMULATED	58%
ABIOTIC	37%

BC LEVEL C = 200 mg/kg

Figure 11

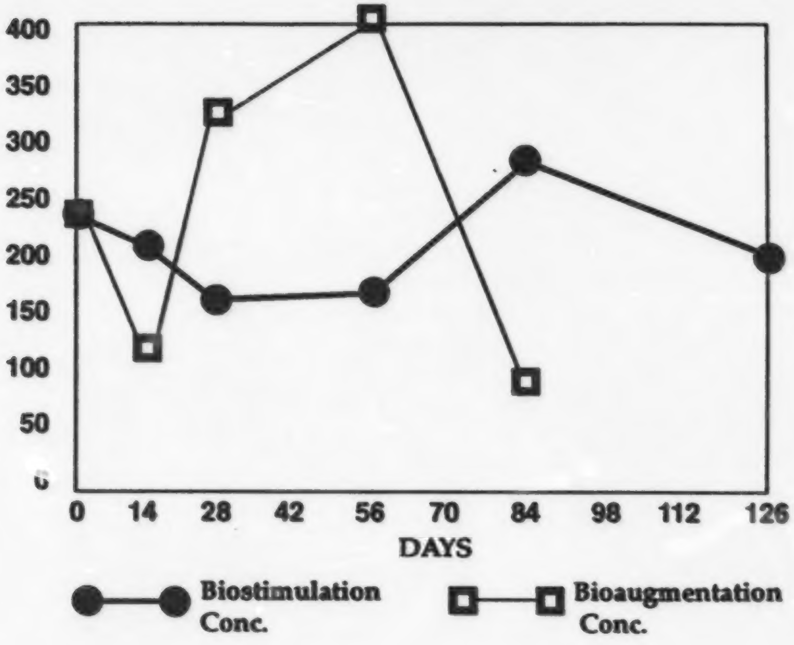
STUDY C
SOIL REACTOR RESULTS
Phenanthrene, SAMPLE 1



REDUCTION	
BIOSTIMULATED	10%
BIOAUGMENTED	74%
ABIOTIC	13%

Figure 12

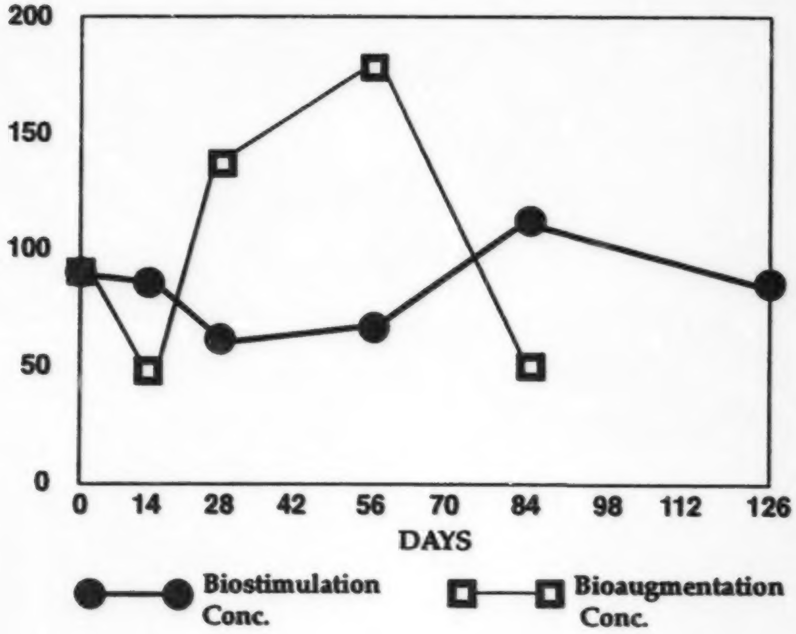
STUDY C
SOIL REACTOR RESULTS
Fluoranthene, SAMPLE 1



REDUCTION	
BIOSTIMULATED	18%
BIOAUGMENTED	64%
ABIOTIC	16%

Figure 13

STUDY C
SOIL REACTOR RESULTS
Benzo (a) pyrene, SAMPLE 1



REDUCTION	
BIOSTIMULATED	8%
BIOAUGMENTED	43%
ABIOTIC	5%

Table 1

AVERAGE CONCENTRATIONS OF SELECTED ORGANICS IN TREATABILITY STUDY SAMPLES

(mg / kg)

Contaminant	Sample 1	Sample 2	Sample 3	Sample 4
Oil & Grease	112,000	10,471	15,786	704
Pentachlorophenol	7	10	136	1
Tetrachlorophenol	2	39	242	< 1
Total PAH	3,375	117	260	151
Naphthalene	877	3	4	5
Phenanthrene	548	16	45	27
Pyrene	343	14	50	20
Fluoranthene	241	16	44	23
Benzo (a) pyrene	118	5	15	9

Table 2

AVERAGE CONCENTRATIONS OF SELECTED INORGANICS IN TREATABILITY STUDY SAMPLES

(mg / kg)

Contaminant	Sample 1	Sample 2	Sample 3	Sample 4
Cyanide	3,729	<1	<1	< 1
Arsenic	9	32	9	89
Copper	391	1,747	377	1270
Lead	254	1887	328	10,548
Nickel	33	76	37	108
Zinc	211	2,367	670	4,273

Table 3

REMOVAL EFFICIENCY OF SELECTED PAHS
SAMPLE 1 X*TRAX TREATABILITY STUDY

Contaminant	Run Feed (ppm)	Product 1 900 F (ppm)	Removal (%)	Product 2 700 F (ppm)	Removal (%)
Naphthalene	1,750	0.41	99.9+	1.4	99.9
Fluorene	150	< (0.0006)	>99.9+	7.2	95.2
Phenanthrene	430	0.29	99.9	1.2	99.7
Anthracene	130	0.057	99.9	0.24	99.8
Fluoranthene	710	0.68	99.9	3.6	99.5
Pyrene	296	0.35	99.9	1.7	99.4
Chrysene	87	0.20	99.8	0.98	98.9
Benzo(a)pyrene	540	< (0.010)	>99.9+	2.2	99.6

Table 4

SELECTED ORGANIC CONTAMINANT CONCENTRATIONS IN TREATED SOIL COMPARED TO TREATMENT GOALS
X * TRAX - SAMPLE 1

Contaminants	Sample 1		BC Remediation Standards Treatability Study Treatment Goals		
	900° F Treated Product (ppm)	Attained	A (ppm)	B (ppm)	C (ppm)
PAHs					
Benzo (a) anthracene	0.18	B	0.1	1	10
Dibenzo (a,h) anthracene	< (0.0028)	A	0.1	1	10
Chrysene	0,20	B	0.1	1	10
Benzo (b) fluoranthene	< (0.001)	A	0.1	1	10
Benzo (k) fluoranthene	0.050	A	0.1	1	10
Benzo (g,h,i) perylene	< (0.0047)	A	0.1	1	10
Pyrene	0.35	B	0.1	10	100
Benzo (a) pyrene	< (0.010)	A	0.1	1	10
Indeno (1,2,3-cd) pyrene	0.033	A	0.1	1	10
Acenaphthene	< (0.005)	A	0.1	10	100
Acenapthylene	< (0.008)	A	0.1	10	100
Anthracene	0.057	A	0.1	10	100
Fluoranthene	0.68	B	0.1	10	100
Fluorene	< (0.0006)	A	0.1	10	100
Napthalene	0.41	B	0.1	5	50
Phenanthrene	0.29	B	0.1	5	50
Total PAH's	2.25	B	1	20	200
CHLOROPHENOLS					
2,4,6-Trichlorophenol	< (0.42)	B	0.1	0.5	5
2,4,5-Trichlorophenol	< (0.66)	C(B?)	0.1	0.5	5
2,3,4,6-Tetrachlorophenol	< (0.66)	C(B?)	0.1	0.5	5
Pentachlorophenol	< (1.8)	C(B?)	0.1	0.5	5
Total Chlorophenols	0	A	0.1	1.0	10

Table 5

TACIUK PROCESSOR - SUMMARY OF THE TEST OPERATING CONDITIONS

ITEM	Units	Sample 1	Sample 3	Sample 1, 2, 4	Sample 2, 4
Test duration	hours	3.5	3.8	3.4	4.4
Feed rates (wet basis)					
Total feed to ATP	tph	2.66	2.94	4.09	3.16
Feed tonnages (wet basis)					
Sample 1	tonnes	1.82		3.61	
Sample 2	tonnes			4.58	6.30
Sample 3	tonnes		11.24		
Sample 4	tonnes			1.13	2.20
Sand	tonnes	7.41		4.52	5.51
Total Feed	tonnes	9.23	11.24	13.84	14.01
Temperatures:					
Reaction zone					
entrance	deg C	521	506	485	468
exit	deg C	554	503	489	496
vapor exit	deg C	587	501	493	523
Combustion zone					
entrance	deg C	718	711	702	764
mid zone	deg C	691	674	677	736
exit	deg C	675	646	616	656

Table 6

TACIUK PROCESSOR - BLEND OF SAMPLES 1, 2, 4, PAH DESTRUCTION AND REMOVAL EFFICIENCY

PARAMETER	Feed (ppm)	Combined Tailings (ppm)	Preheat Water (ug/L)	Sour Water (ug/L)	Emissions (ug/m3)	DRE (%)* All Product Streams
Acenaphthene	ND	ND	ND	ND	TR	100
Acenaphthylene	6.4	ND	ND	ND	NA	100.00
Anthracene	17	ND	ND	ND	6.5	99.98
Benzo(a)anthracene	12	ND	ND	ND	TR	100.00
Benzo(b+k)flouranthene	46	ND	ND	ND	NA	100.00
Benzo(a)pyrene	22	ND	ND	ND	NA	100.00
Benzo(g,h,i)perylene	TR	ND	ND	ND	NA	100
Chrysene	16	ND	ND	ND	TR	100.00
Dibenzo(a,h)anthracene	TR	ND	ND	ND	NA	100
Fluoranthene	54	ND	ND	TR	41.7	99.95
Fluorene	TR	ND	ND	ND	TR	100
Indeno(1,2,3,c,d)pyrene	12	ND	ND	ND	NA	100.00
Naphthalene	29	ND	ND	52.3	85.2	99.79
Phenanthrene	52.4	TR	ND	ND	124.5	99.85
Pyrene	42.4	ND	ND	TR	20.5	99.97

NA - Not Analyzed TR - Trace
ND - Not Detected * - Alberta Environment Regulations

Table 7

TACIUK PROCESSOR MASS OF WATER AND OIL PRODUCTION

	Feed (kg)*	Water (kg)	Oil (kg)
Test 1 (Sample 1)	9,000	700	200
Test 2 (Sample 3)	11,000	1,800	110
Test 3 (Blended Sample)	14,000	2,200	Net Loss
Test 4 (Blended Sample)	14,000	2,600	Net Loss

* wet basis

Table 8

TESTING PROTOCOLS FOR EVALUATING THE PERFORMANCE OF STABILIZATION / SOLIDIFICATION TECHNOLOGIES

TEST	METHOD
• Total organic carbon	Flame ionization
• Bulk density	WTC Method 2
• Specific gravity	WTC Method 3b
• Moisture content	WTC Method 4
• 7 day leach test (water)	WTC Method 9
• Sequential batch test(water) for anions and organics	ASTM D 4739-88
• Sequential batch test (increasingly agressive media)	WTC Method 12

Table 8
(continued)

TESTING PROTOCOLS FOR EVALUATING THE PERFORMANCE OF STABILIZATION / SOLIDIFICATION TECHNOLOGIES

TEST	METHOD
• Dynamic leach test (monolith only)	ANSI / ANS 16.1
• Hydraulic conductivity (monolith only)	WTC Method 5
• Compressive strength (monolith only)	WTC Method 6
• Freeze / thaw or Wet / dry (monolith only)	ASTM D 4842 - 89 ASTM D 4843 - 89
• Acid neutralization capacity	WTC Method 11
• Biodegradability (biological growth)	ASTM G21 - 70, G 2276

REFERENCES

1. British Columbia Standards for Managing Contamination at the Pacific Place Site, British Columbia Ministry of Environment, Waste Management Program, May 2, 1990.

2. Interim Protocol for Delisting Special Wastes, British Columbia Ministry of Environment, Environmental Protection Division, July 10, 1990.

BIOGRAPHIES OF THE AUTHORS

Biography for Sandra S. Whiting.

Sandra Whiting is a Project Scientist with SCS Engineers, Bellevue, Washington (doing business as Stearns and Conrad Engineers in Vancouver, British Columbia). SCS Engineers is an environmental engineering consulting firm specializing in solid and hazardous waste. Ms. Whiting holds a Bachelors degree in Biology from Western Michigan University and a Masters degree in Environmental Planning from the University of Washington. She has over 10 years of experience in the environmental field with substantial expertise in hazardous waste management. Prior to joining SCS, Ms. Whiting held various positions in local and state government, including the Washington State Department of Ecology. She has been involved with the Pacific Place Soils Remediation Project for nearly 3 years and has had primary responsibility for the treatability study program.

Biography for R.H. Ferguson.

Mr. Ferguson is presently the Director of Standards and Technical Services for the Environmental Protection Division of the British Columbia Ministry of Environment, Lands and Parks. Among other duties, Mr. Ferguson is responsible for the management of the treatability study program for the Pacific Place Soils Remediation

Project. Mr. Ferguson has held a variety of positions with the Ministry since 1965, rising to the position of Director of Waste Management in 1979. In 1990, he was seconded from the Ministry to the B.C. Hazardous Waste Management Corporation, where he served as the Vice-President and Director of Engineering and Technical Services until returning to the Ministry in 1991. He earned a Bachelor of Science degree in Civil Engineering from the University of Alberta in 1961 and worked with the Alberta Department of Public Health from 1961 to 1965.

13.0

Remediation Activities at the Canada Creosote Site
Calgary, Alberta, Canada

BY:

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Alberta Environment

Alan M. Hingston
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Alberta Environment

ABSTRACT

The Canada Creosote Site is located on the south bank of the Bow River just west of downtown Calgary, Alberta, Canada. It was used as a wood preserving operation from the mid 1920s to mid 1960s. Numerous studies have been conducted since 1988 to establish hydrogeological conditions and characterize contamination at the site, which is one of the largest orphan contaminated sites in Canada. Siltstone bedrock, about 6 - 9 m beneath the site, is overlain by 3 - 8 m of sand and gravel, and up to 4 m of fine grained material. The watertable is in the gravel layer and has a slight slope towards the river. Soils and groundwater beneath the site are extensively contaminated with wood preservatives. Large pools of dense non-aqueous phase liquids (DNAPLs) are present on the bedrock beneath the property. The pools extend out under the Bow River in the riverbed gravels, probably at least 650 m along the river.

Several remediation strategies have been developed to address site and riverbed contamination. Options being considered for the site contamination include a containment wall and groundwater control system, DNAPL pumping system to remove free creosote and in-situ soil washing and biodegradation. Addressing the riverbed contamination is more complex since work is required in the river. An innovative pilot test was conducted which involved using a cofferdam to isolate a portion of the river, excavation and washing of contaminated gravels, treatment of wastewater and return of clean gravels to the excavation site.

13.1

Remediation Activities at the Canada Creosote Site
Calgary, Alberta, Canada

Introduction

The Canada Creosote site is one of the largest contaminated orphan sites in Canada. This paper presents a background on the site, describes the nature and extent of contamination, and outlines some remediation options being considered.

HELP Project

The HELP Project was initiated by Alberta Environment in September 1986 to inventory, assess and take corrective action at both active and abandoned industrial landfills and plant sites in Alberta. Information on sites was obtained from a number of sources including media response, government records, industry questionnaires and local governments. Under the inventory phase, 682 sites were identified; 213 of the sites were active, 427 were inactive and 42 had been abandoned. A comprehensive ranking system was developed to assign a numerical score to all sites based on potential impact to human health and the environment.

During the assessment phase, 13 of the 42 orphan sites were identified as requiring investigation to determine if they posed a threat to human health and/or the environment. Orphan sites are those where no party could be identified or held responsible for decommissioning. Six of the sites are former wood preserving operations, while seven are former refineries or oil/chemical disposal sites. The most significant of the orphan sites is the former Canada Creosote site in Calgary.

Canada Creosote Site History

The Canada Creosote site is located on the south bank of the Bow River just west of downtown Calgary. Main features of the plant site are shown in Figure 1. Wood preserving operations at the site, which used a pressure treating process to inject wood preserving compounds into raw wood, commenced in 1924 and continued uninterrupted until 1962. The compounds included coal tar, creosote and creosote mixtures. Pentachlorophenol in oil was used to treat poles during the 1950s. After treatment, the wood was removed from the cylinders and dripped on unprotected soil.

Wastes from the operation included process and runoff water which was collected in settling ponds and/or open storage tanks, and solid wastes and sludges from the main treater building sump. Wood preserving chemical agents were recovered from the settling ponds by skimming oil off the settling ponds surface and also by removing products from the pond bottom. The remaining water was then discharged to the river. Extensive landfilling activities occured on the site particularily between 1925 and 1956.

Chemical agents used in the wood preserving process were stored on site in storage tanks located south of the treater building. The area immediately to the east of the main treater building is assumed to have been a drip pad area in which free liquid was allowed to drip upon the ground surface. Surface deposits of creosote and tar were evident along the entire length of the cylinder track area. On at least one occasion major spills occurred when a railroad tank car entered the property with the valve open. Most of the liquid product spilled would either infiltrate or be soaked up with sawdust and sand.

By 1963 the site had been reclaimed and the surface grade facilities removed. Site reclamation included breaking up of the building foundation and burying them on site. Most of the equipment was moved to another wood preserving facility in Cochrane, Alberta. The Canada Creosote site has been redeveloped, and is occupied by two car dealerships and is crossed diagonally by a major roadway (Figure 2).

Geology and Hydrogeology

The site is underlain by fill, sand and gravel, and siltsone bedrock. Fill is present across the entire site, and ranges in composition from predominantly sand and gravel, to mostly silt with some sand. The fill thickness varies from approximately 1 to 6 m. Abundant wood chips are present in the fill across much of the site.

Immediately underlying the fill, and extending down to the bedrock surface is an alluvial deposit of sand and gravel. The thickness of the sand and gravel layer is typically in the range from 1 to nearly 5 m. Beneath the river along the south bank, immediately adjacent to the site, the sand and gravel is typically 1 to 2 m thick. On the north side of the river, the sand and gravel contains clay lenses.

Bedrock in the study area is comprised of fractured siltsone. Distinct erosional features in the bedrock surface have been identified either by drilling or geophysical surveys. The depressions in the bedrock surface probably represent erosional features caused by the river at sometime in the past before it reached its present stage. The bedrock surface slopes generally towards the river. In the western portion of the site, the bedrock slope is to the north, whereas in the eastern portion it dips to the northeast. A bedrock high has been identified beneath car dealership A. Surrounding this high, several depressions nave been identified in the bedrock surface, the most significant of which is a circular depression which is approximately 2 m deep located in the eastern part of the property.

Groundwater is typically at the depth of 4 - 7 m below ground surface across the site area. The direction of groundwater flow is generally towards the river; however, in the western portion of the site, there is a strong component of the hydrogeologic gradient which parallels the river channel. In the eastern portion of the site the hydrogeologic gradient is directed towards the river and it is over this portion of the site (some 250 m in length) where the majority of groundwater discharge from the site to the river is expected to occur (Figure 3). The average hydrogeologic gradient indicated by the groundwater contour map is 0.01.

The hydraulic conductivity of alluvial sands and gravels is typically in the range from 1 x 10^{-5} to 1 x 10^{-2} m/sec. Using a hydraulic gradient of 0.01, an average hydraulic conductivity value of 4 x 10^{-4} m/sec, and an assumed porosity of 0.3, an average groundwater velocity of approximately 400 m/year is estimated. Similarly, using the same parameters, a groundwater flux of approximately 130 m^3/year is estimated through a 1 m^2 of cross sectional area of the alluvial sands and gravels.

Nature and Extent of Subsurface Contamination

Creosote and pentachlorophenol have been identified as the major compounds used in the wood preserving process at the former Canada Creosote site. Creosote is a distillate of coal tar, the major component of which are polyaromatic hydrocarbons (PAHs). Chemical analyses of free liquid creosote samples from the site indicate that aliphatic and olefinic hydrocarbons, flouranthene and pyrene make up a major portion of compounds in the creosote (Table 1 and 2). Creosote and creosote/petroleum oil mixtures used in wood preservation facilities are immiscible in water, and depending upon the composition and mixture ratio, form a liquid which may be heavier or lighter than water. At 4°C the density of creosote at the site varies from 1.052 to 1.056 g/mL for

DNAPL (dense non-aqueous phase liquids) and from 0.9479 to 0.9956 g/mL fro LNAPL (light non-aqueous phase liquids).

Investigations at the site have found the creosote occurs primarily as DNAPL pools within the alluvial sands and gravels underlying the site, tending to accumulate in bedrock depressions. The siltstone bedrock occurs at an approximate depth of 7 to 10 m below ground surface. The main pool lies beneath the watertable and encompasses an area in the order of 31,000 m^2 and is estimated to contain 4,750 m^3 of creosote. The pool occurs in the vicinity of the former treater building and extends eastwards, a linear distance of over 300 m, to beneath the Bow River (Figure 3). There is evidence that creosote from the site has migrated to the area north of the river.

Free liquid creosote in the LNAPL form has been observed floating upon the watertable in a number of monitoring well locations. Generally, this creosote is lighter in colour and less viscous. The LNAPL occurs as an elongate plume approximately 240 m and 30 - 50 m wide parallel to and adjacent the west bound roads of Bow Trail (Figure 3).

Free creosote in the DNAPL form has been detected in sands and gravels beneath the river. Measurements in monitoring wells installed in the bed of the river indicates that the DNAPL creosote plume is 2 m thick in the southwest corner of the bermed area (Figure 1). Monitoring wells located some 70 - 180 m up stream of the bermed area, 50 m out from the south river bank indicate the presence of less than 2 m of DNAPL creosote in the river bed sands and gravels immediately above the bedrock. Observations made during the drilling and installation of monitoring wells and well points in the riverbed indicated that creosote contamination of the river bed sands and gravels may extend over a 650 m long stretch of the river.

In the fall of 1989 the discovery of seepage of creosote in the Bow River prompted an emergency response including suction of DNAPL material from the river and construction of a berm to isolate the seepage area from the river flow. It is believed the seepage of creosote is influenced by the hydraulic gradient and river water temperature. The creosote tends to more mobile in late summer/fall when river flows are lower and the water temperature is at a maximum.

Creosote also occurs as residual material in the soil on the fringes of the free-liquid pool on land and also along approximately 300 m of the south shore of the Bow River. Distributance of the river bed through walking or throwing stones causes fine particulate creosote to come to the water surface and form a characteristic hydrocarbon sheen. Observation of the creosote liquid in water indicates that the cohesion of the creosote is greater than the adhesion between the creosote and the soil particles. This property causes the creosote to form beads or blobs in water.

Groundwater contamination beneath the site is associated with dissolution of DNAPL and LNAPL creosote. Dissolved constituents in the groundwater consist of PAHs and phenolic compounds (Table 3). The main areas of groundwater contamination tend to be coincidental with the onsite DNAPL and LNAPL plumes. Monitoring wells installed along the south bank of the river indicate a zone of contaminated water discharge into the river approximately 250 m wide (Figure 3).

Remediation Strategy

Basic elements of a proposed remediation strategy for the site are as follows:

- the containment berm in the Bow River will be maintained to facilitate collection of creosote seepage on the river bed. The berm will also provide a control area where various remedial trials can be tested without undue impact on the river.

- install DNAPL and LNAPL recovery systems on land to initiate pumping out of free creosote. In designing effective pumping systems, the unique viscosity and surface tension characteristics of the creosote will need to be considered. Dual drain lines (horizontal wells) will be favored over vertical wells.

- install a containment wall to physically isolate creosote contamination beneath the former site area from the river and local groundwater system. A combination of caisson and jet grouting methods are proposed due to the complex arrangements of major utilities that lie both over and under the site. Groundwater control measures will also be required.

- conduct soil washing trials (on sands and gravels) and bioremediation treatability studies on solid and fluid waste streams. The studies will be initially bench scale and proceed rapidly to field pilot if proven feasible.

- install vapour control systems if necessary to protect car dealerships against possible adverse effects of soil vapors generated by enhanced biodegradation of residual creosote within the containment wall.

- construct on-site solids and fluids storage facilities and associated bioremediation plant facilities, also any offsite treatment and/or disposal facilities should they be required.

- excavate and wash contaminated gravels from the river bed using a staged cofferdam system. A pilot scale study was conducted in 1991 which involved the excavation and cleaning of contaminated river bed materials and treatment of waste liquid streams. The pilot scale study is described in detail in a subsequent paper.

Conclusion

Wood preserving activities at the former Canada Creosote site have resulted in widespread soil and groundwater contamination by wood preserving compounds. A proposed remediation strategy has been developed to address both on land and river contamination. A detailed risk assessment study will be used to guide the remediation process. By using a risk assessment study, remediation activities can be directed at contamination components posing the greatest risk to human health and the environment. In addition the risk associated with each remediation option can be evaluated.

Acknowledgements

Most of the site characterization work and evaluation of remediation strategies was capably conducted by Golder Associates Limited under contract to Alberta Environment.

Biographical Sketches

Walter J. Ceroici is presently Quality Monitoring Section Head in the Wastes and Chemicals Division of Alberta Environment. He received a B.Sc. (Honours) in Geology from the University in Edmonton, Alberta, Canada and and M.Sc. in Earth Sciences from the University of Waterloo, Ontario, Canada. In the past, he has been employed by the Alberta Research Council and Monenco Consultants Limited as a Senior Hydrogeologist. His current responsibilities include the investigation of soil and groundwater contamination problems and remediation implementation.

Alan Hingston is currently the Project Manager of the Help End Landfill Pollution (HELP) Project, a project of Alberta Environment to inventory, assess and clean-up former industrial landfills or plant sites in Alberta. He has a Master's Degree in Hydrogeology from University College, London and seven years experience in the water industry in the U.K. Since coming to Alberta in 1981 he has worked in the consulting industry. His main responsibility at present is supervising the work of consultants investigating 13 sites, mainly former wood preserving operations or oil refineries.

Table 1

Major Chemical Components of Creosote (DNAPL Form)

Major Components	(3 samples) RANGES (PPM)
C_{11} to C_{28} aliphatic and olefinic hycrocarbons	79,000 - 97,000 (htw) 171,000 - 460,000 (ltw)
fluoranthene/pyrene	78,000 - 100,000
benzo(a)anthracene/chrysene	23,000 - 53,000
benzo(b)fluoranthene/benzo(k) fluoranthene	35,000 - 45,000
methyl fluoranthene/pyrene	23,000 - 32,000
methyl fluorene	18,000 - 32,000
methyl dibenzofuran	17,000 - 25,000
C_3 subst'd naphthalene	12,000 - 25,000

htw - heavier than water
ltw - lighter than water

Table 2

Chemical Constituents of Creosote

	TARGET PAH COMPONENTS	
	DNAPL (3 samples) ppm	LNAPL (3 samples) ppm
Naphthalene	96,000 - 120,000	2,900 - 54,000
C1 - naphthalene	31,000 - 38,000	16,000 - 36,000
C2 - naphthalene	30,000 - 49,000	47,000 - 66,000
Acenaphthylene	1,700 - 2,500	1,100 - 1,500
Acenaphtene	12,000 - 14,000	6,600 - 9,300
Fluorene	17,000 - 19,000	10,000 - 13,000
Phenanthrene/ Anthracene	9,200 - 9,700	6,800 - 77,000 (38,000 BH 4)
Dibenzofuran	4,000 - 4,500	2,000 - 3,100
Pentachlorophenol	1,600 - 3,100	3,000 - 4,400
Carbazole	1,200 - 1,300	Not detected
Methyl Phenanthrene/ Anthracene	1,500 - 8,900	1,200 - 9,500
Benzo(a)pyrene	1,700 - 2,600	ND* - 1,700

*ND - Not detected

NOTE: Data obtained from chemical analysis of free liquid obtained from monitoring wells

Table 3

Major Organic Components of Contaminated Groundwater

(10 samples)

	Range
PAH's (ppb)	
Naphthalene	0.17 - 6,100 ppb
C1 - naphthalene	0.34 - 1,300
C2 - naphthalene	0.21 - 800
Acenaphthylene	0.34 - 65
Acenaphthene	1.7 - 430
Fluorene	0.25 - 440
Phenanthrene/Anthracene	0.48 - 1,200
Dibenzofuran	ND (<0.10) - 120
Carbazole	ND (<0.20) - 170
Methyl Phenanthrene/Anthracene	0.46 - 170
Benzo(a)pyrene	ND (<0.10) - 83
PHENOLS (ppb)	
Phenol	ND - 63
2,4 Di-methylphenol	ND - 540
2,4 Di-chlorphenol	ND - 5.2
Pentachlorophenol	ND - 1,400
2,4,6 trichlorphenol	ND - 7.8

ND - Not detected

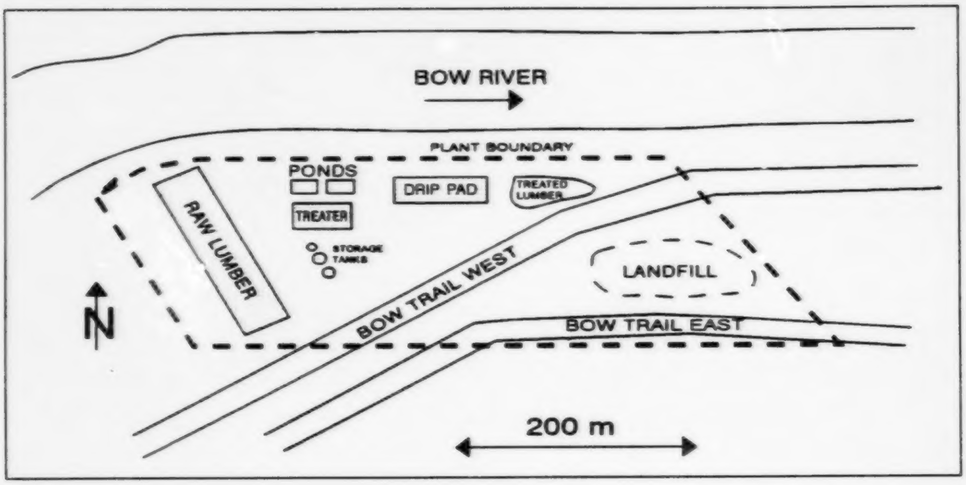

BOW RIVER
PLANT BOUNDARY
PONDS
DRIP PAD
TREATED LUMBER
TREATER
STORAGE TANKS
RAW LUMBER
BOW TRAIL WEST
LANDFILL
BOW TRAIL EAST
N
200 m

Figure 1. Canada Creosote Plant Site Features

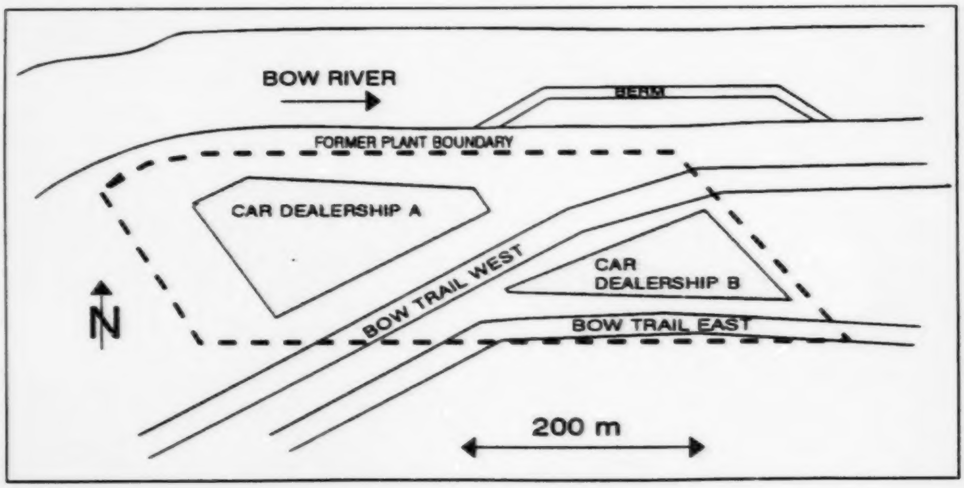

BOW RIVER
BERM
FORMER PLANT BOUNDARY
CAR DEALERSHIP A
CAR DEALERSHIP B
BOW TRAIL WEST
BOW TRAIL EAST
N
200 m

Figure 2. Site Redevelopment Features

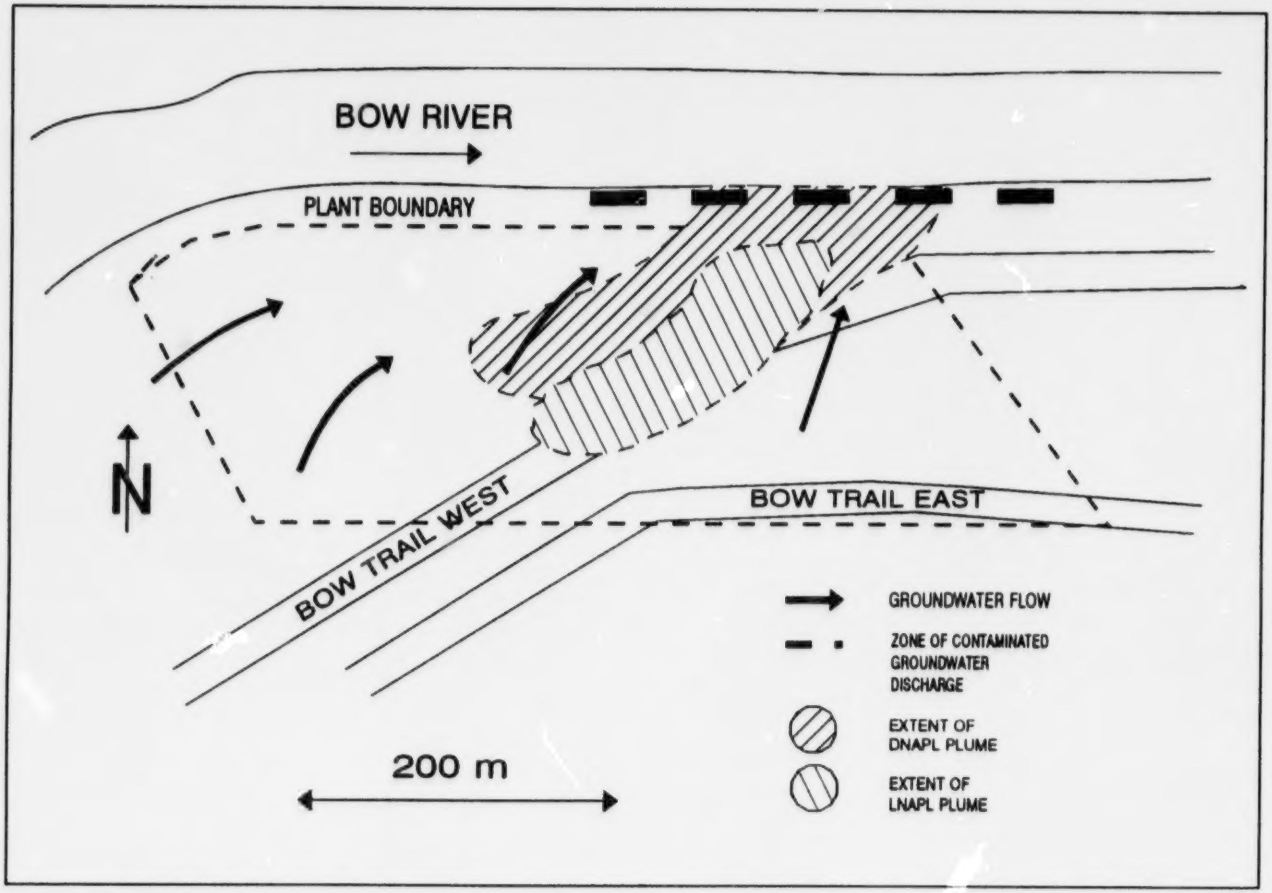

BOW RIVER
PLANT BOUNDARY
N
BOW TRAIL WEST
BOW TRAIL EAST
GROUNDWATER FLOW
ZONE OF CONTAMINATED GROUNDWATER DISCHARGE
EXTENT OF DNAPL PLUME
EXTENT OF LNAPL PLUME
200 m

Figure 3. Groundwater Flow and Approximate Extent of NAPL Plumes

REMEDIATION ACTIVITIES AT THE CANADA CREOSOTE SITE IN CALGARY

FALL 1991 PILOT PROGRAM

BY
COLIN. R. BERESFORD, P.ENG.
PROJECT MANAGER
ACRES INTERNATIONAL LIMITED.

ABSTRACT

The Fall 1991 Pilot Program at the Canada Creosote site in Calgary was developed to investigate alternative remediation techniques for creosote contamination of sub-river gravels.

Three alternative cofferdam cell construction methods were investigated to assess which would provide the most effective and environmentally acceptable solution. Excavation was carried out within the secure area formed by the cofferdam cells to provide a source of creosote-contaminated river gravels. A full-size gravel washing plant was established at the site to determine the best combination of equipment and operating procedures for cleaning these contaminated gravels.

A water treatment plant, capable of treating 4 L/sec, was set up at the site to recycle water needed for the gravel washing operation.

A comprehensive sampling and analysis program was initiated for process, environmental and quality assurance assessment and monitoring.

To ensure worker safety, rigorous industrial hygiene and construction safety plans were developed and their implementation and effectiveness was monitored on site.

The pilot work was taken from conceptual design to completion in five months. All major objectives were achieved on time and within budget. Detailed assessment of the collected data will be completed in conjunction with a major risk assessment program planned for 1992.

14.2

CANADA CREOSOTE CALGARY
FALL 1991 - PILOT PROGRAM

Introduction

This project was funded jointly under an agreement between the Governments of Canada and Alberta. The agreement, which covers implementation of remedial measures of orphan contaminated sites, and the development and demonstration of remedial technologies, is administered by Alberta Environment.

The work carried out for the Canada Creosote Fall 1991 Pilot Program was directed at investigating alternative river remediation options and providing data for ongoing risk assessment studies. Acres International Limited, under the direction of the HELP project team, developed and managed the pilot work as a whole and provided control and supervision for site work.

Principal elements of the program were:

- cofferdam construction pilot, and
- gravel washing and excavation pilot.

Other important elements included:

- water treatment plant,
- sampling and analysis,
- site facilities,
- waste material handling,
- emergency response, and
- occupational health and safety.

- Pilot Gravel Washing Contract, and
- Sampling and Analysis Contract.

Pilot Cofferdam Contract

In the summer of 1991, Monenco Consultants Limited carried out a study to review strategies for excavating contaminated gravels from the Bow River adjacent to the site. As an integral part of this study, they made recommendations for a pilot program to investigate alternative cofferdam construction methods.

The Pilot Cofferdam Contract was prepared jointly by Acres and Monenco and, following a tender process, Hazco Engineering & Contracting Ltd. was awarded the work. Monenco was subsequently appointed to monitor the installation of the cofferdam on site.

The pilot cofferdam was 35 meters long by 25 meters wide and incorporated three trial sections:

- a pervious fill berm,
- a pre-cast concrete cell, and
- a driven sheet-pile cell.

A one-meter wide impervious bentonite slurry wall cut-off was installed around the perimeter of the cofferdam. Typical cross-sections for the trial cofferdams are shown in Figure 2.

The pilot cofferdam was within the existing berm, which was built in 1988 around a confirmed source of creosote intrusion from the south bank of the Bow River. This location ensured the presence of heavily contaminated river gravels and provided additional protection against potential releases of contaminants to the river during the pilot work.

The following site facilities were also provided under this contract:

- a bermed, lined enclosure to contain the gravel washing and water treatment equipment,
- a secure, fenced office and lay-down area together with accesses, and
- an existing bicycle path which was rerouted around the site perimeter.

In addition to information on alternative construction methods, the cofferdam also provided a protected location to excavate 500 m^3 of contaminated river gravels required for the gravel washing pilot.

Interim Mitigation Contract

CH2M Hill Engineering Limited carried out a study into water treatment alternatives for creosote-contaminated water in the summer of 1991. A basic concept for a pilot water treatment plant was presented in their report. They subsequently monitored the operation of the water treatment plant on site.

The Interim Mitigation Contract was prepared by Acres with the following objectives:

- to establish a water treatment plant including detail design,
- to provide an emergency response capability,
- to handle and dispose of contaminated wastes generated during the pilot work,
- to provide site facilities including offices, wash trailer and utilities, and
- to provide security, first aid and janitorial services.

Tenders were called in August 1991 and Hazco was awarded the Contract.

The water treatment train consisted of:

- five dirty water/settling tanks,
- clarifier,

- bag filter,
- Klensorb column,
- granular activated carbon column, and
- three semi-clean and two clean water storage tanks.

A schematic of the water treatment plant is given in Figure 3. Water for the gravel washing was taken in various combinations from the clean and semi-clean storage tanks. After use it was transferred to the dirty water storage tanks. From there it was recycled through the water treatment plant to the clean and semi-clean tanks for reuse. One clean water tank was supplied with a propane heater to enable gravel washing tests to be performed with warm water.

A combination of Betz 1192 and 1195, cationic liquid polymers, and Betz 1115L, a high molecular weight anionic flocculant, were used to enhance the flocculation of solids and non-aqueous phase liquids.

The plant, capable of processing contaminated water at a rate of 4 L/s, operated on 29 of the 36 days it was available, and processed 1,950 m^3 of contaminated water at an average of 70 m^3 per day.

From the beginning of November, freezing weather conditions caused considerable problems to the water treatment process, and heating and hoarding were installed to enable work to continue.

Every effort was made to maximize useful information from the water treatment plant; however, its principal purpose was to provide a supply of recycled water to the gravel washing pilot plant. Because of this, and for reasons of economy, a fairly simple, robust treatment plant was installed. Although some problems were experienced with handling high suspended solid contents, the plant performed its function satisfactorily.

Pilot Gravel Washing Contract

The Alberta Research Council carried out bench scale testing of alternative gravel washing methods as a part of their Gravel Washing Study in 1991/92. Results from this study were considered in establishing the scope of the Pilot Gravel Washing Contract.

The Pilot Gravel Washing Contract was developed by Acres to provide a comparison of the effectiveness of various combinations of conventional gravel washing equipment in cleaning creosote-contaminated river gravels. Tenders were called in August 1991 and Burnco Rock Products Limited was awarded the Contract.

Contaminated river gravels were excavated from the pilot cofferdam using a back-hoe/loader combination and fed into a 200 mm grizzly feeder to remove boulder-size stones. The gravels were then passed along a conveyor to a 5 x 18 ft vibrating, 3-deck screen. The screen deck washed and processed the 200 mm down material into three fractions: 200 x 75 mm, 75 x 3 mm, and 3 x 0 mm. A schematic of the gravel washing pilot is given in Figure 4.

The 75 x 3 mm fraction was transferred via a gravity chute to the coarse material screw. This consisted of combined paddles and screw flights to provide scrubbing, scouring and agitation. Water was added and, with mechanical agitation, the gravel was washed a second time.

The 3 x 0 mm fraction was gravity fed along with wash water to a fine material screw where it was washed a second time. This fraction was considered to be a contaminated waste and was contained in storage bins.

Tests were carried out on the 75 x 3 mm material using a tumbler/trommel with a capacity of 15 m^3/hr. This consists of a rotating drum, part of which provides a tumbling action and the remainder acts as a screen. Water is added with the gravel at one end and the machine imparts an abrasive washing action. Three millimetre minus material is passed out with the contaminated wash water through the rotating screen. Cleaned gravels pass out through the end of the trommel.

Thirteen gravel washing and rewashing tests were performed using different combinations of equipment, water quantity and quality, and feedstock material. The daily production was limited by the availability of recycled wash water. The average rate of gravel washing was 50 tonnes per day with a maximum of 300 tonnes per day. The total quantity of contaminated gravel excavated and treated was 1000 tonnes and of this 100 tonnes was rewashed.

In addition to the material separated and washed through the gravel washing plant, a significant amount of fine sludge accumulated in the dirty/settlement tanks and in the excavation area within the cofferdam. This material was removed and eventually passed through a centrifuge to reduce the water content to enable it to be transported and stored as solid waste. Most of the creosote found on site is associated with this dewatered sludge and in the 3 x 0 mm fine sand generated from the gravel washing operation.

Sampling and Analysis

The Alberta Research Council was responsible for the collection and analysis of gravel, process liquids, surface water and air quality samples. The sampling and analytical program that was carried out had three components:

- Process Evaluation Sampling to assess the effectiveness of the gravel washing and water treatment systems. This involved:
    - collection of gravel samples or fines from each stage in the washing process to provide data to assess the degree of residual hydrocarbon contamination, and

  - collection of water samples from the effluent from each stage of the water treatment system to provide data to evaluate the effectiveness of the water treatment system.
- Environmental monitoring to provide data to assess the impact of the processing operation on air quality in the Bow River valley at the test site and in the surrounding area and on the water quality in the Bow River.
- Analytical supervision and quality assurance/quality control.

In addition, the sampling program included collection of water samples for bioassay evaluation and of water discharged to the City of Calgary sanitary sewer system. Water samples from the Bow River were collected weekly by Alberta Environment with analytical supervision and QA/QC of these samples by the Alberta Research Council.

Gravel samples were collected in a time-integrated fashion from five locations in the processing stream. In addition, time-integrated samples of contaminated liquids and fines (−3 mm) were collected from the outlet of the plant before settling.

Wastewater samples were collected from six locations in the process stream once a day for each batch of wastewater that was processed. All wastewater samples were analyzed for Total Organic Carbon or Oil and Grease and selected samples were analyzed for a target list of PAHs including Pentachlorophenol.

The air quality monitoring program was designed to evaluate:

- the level of hydrocarbon vapors in the working area,
- the dispersion of contaminated air from the pilot site,
- off-site hydrocarbon levels related to pilot operations, and
- particulate contamination produced by pilot operations and their dispersion from the site.

On-site air quality monitoring was done with an HNU Model 311 portable gas chromatograph equipped with a photoionization detector. Detection limits were 20 ppb for naphthalene and 2 ppb for benzene-based hydrocarbons. Samples were taken by drawing air into Tedlar bags using a personal sampling pump. Samples were collected during operations from 16 on-site locations, within 100 m of the gravel washing plant.

Composite air quality samples were collected daily from two on-site and four off-site locations using glass traps containing Tenax or Carbotrap. Sampling periods ranged from 6 to 10 hours. Samples were thermally desorbed and extracted in n-hexane for analysis of a list of target compounds GC/MS.

Particulate air sampling was done using Hi-Vol samplers at two on-site and four off-site locations. Samples were collected daily, representing 6- or 10-hour periods. Mass of particulates was determined for all samples. Five sampling days were selected for extraction and analysis of a list of target PAH compounds using GC/MS.

For the duration of the pilot program, wind speed and direction was monitored continuously with a recording wind system located on the berm just east of the gravel plant. Temperature, wind speed and direction were measured at 1-minute intervals, and the 5-minute means and standard deviations were recorded using a data logger.

Occupational Health and Safety

Provisions for occupational health and safety were considered to be of prime importance during the pilot work on site. Certified Industrial Hygiene Consulting Limited was engaged to provide industrial hygiene services. Its responsibilities included preparation of an Occupational Health and Safety Plan — Industrial Hygiene, and monitoring its implementation on site. As a general guideline the United States National Institute for Occupational Safety and Health (NIOSH) Guidance Manual for Hazardous Waste Site

Activities (1985) was used to develop this plan. Acres prepared an Occupational Health and Safety Plan — General Construction and monitored its implementation on site.

All full-time workers were obliged to complete a pre-placement medical questionnaire and screening and attend a Health and Safety training session. A WHMIS refresher course was available to all personnel.

The site was separated into three zones:

- support zone consisting of areas such as offices and a canteen which were regarded as non-contaminated
- intermediate security zone where decontamination of workers and equipment occurred, and
- exclusion zones where contamination of workers and equipment could occur.

The Plan called for different personal protection requirements within the exclusion zones depending on the nature of work and level of contamination. Minimum protective clothing consisted of, safety helmet, neoprene boots with steel toe caps, eye protection, Tyvek suits and inner/outer glove combination. Respirators were available to everyone on site at all times.

Ambient air monitoring for worker protection was maintained continually. Two thresholds were established in the Plan for respiratory protection:

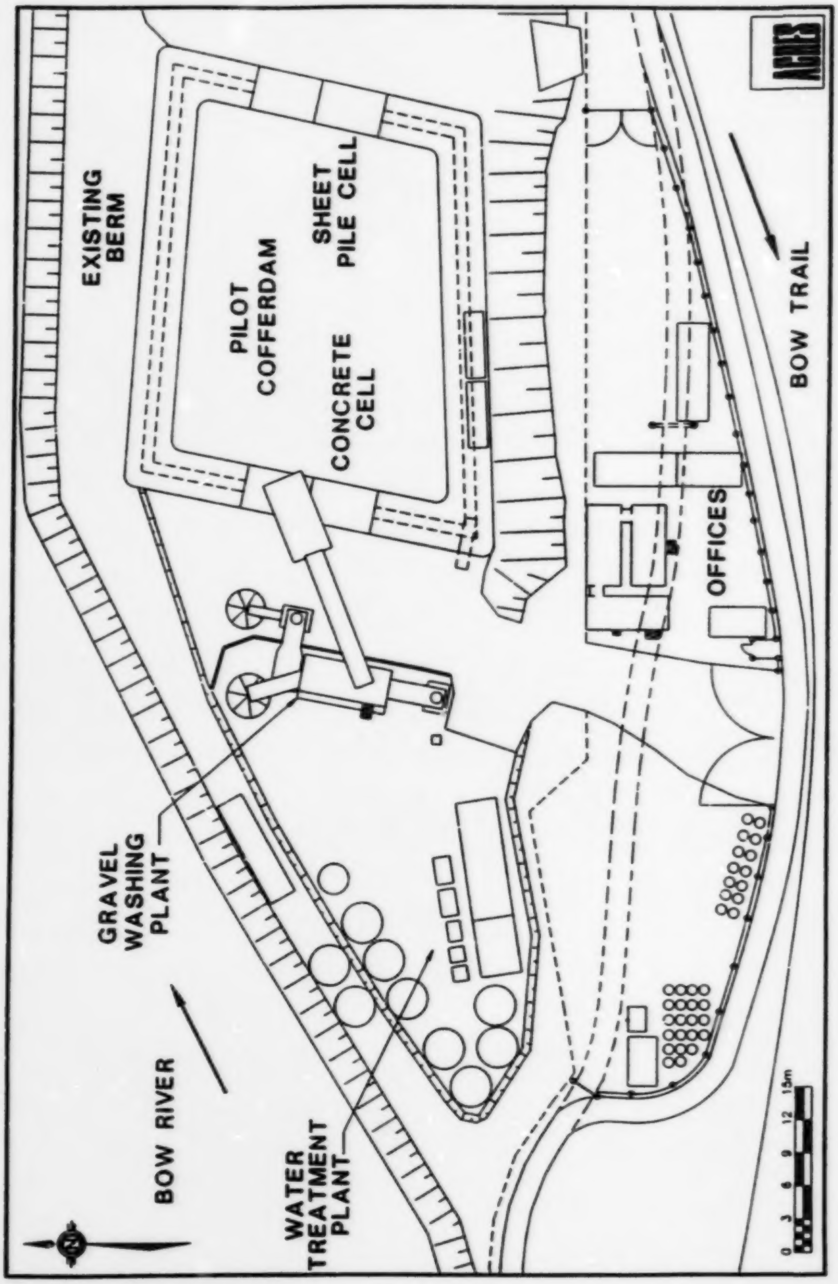
- 10 ppm of total hydrocarbon concentration when wearing of respirators became mandatory, and
- 50 ppm total hydrocarbon concentration when the affected area would be evacuated.

A comprehensive decontamination procedure was established in the Plan which included a requirement for workers leaving an exclusion zone to shower at the end of each shift.

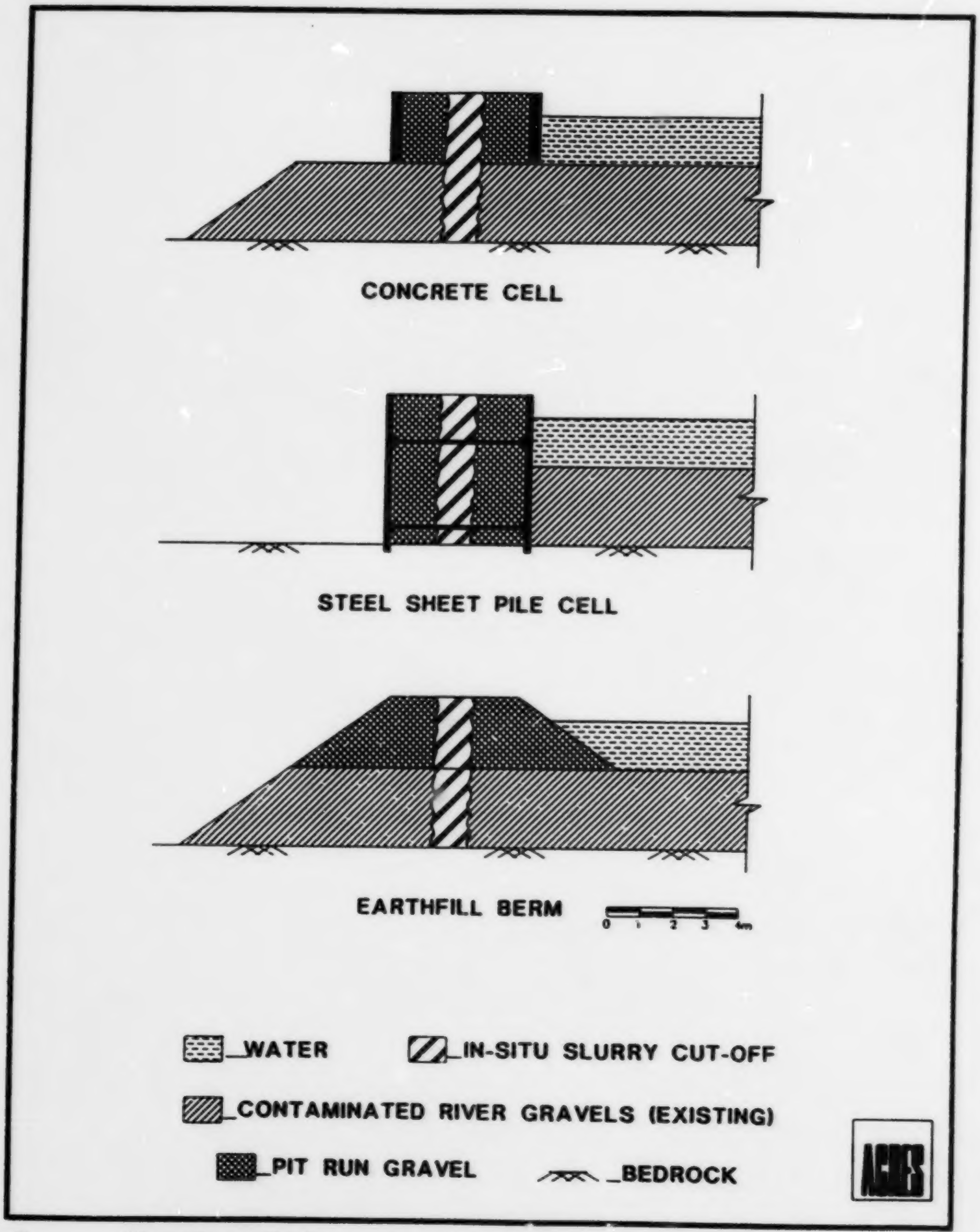
Close liaison and consultation were maintained with Alberta Occupational Health and Safety both prior to and during the pilot work and provisions made either equalled or exceeded the requirements of the Act.

Summary

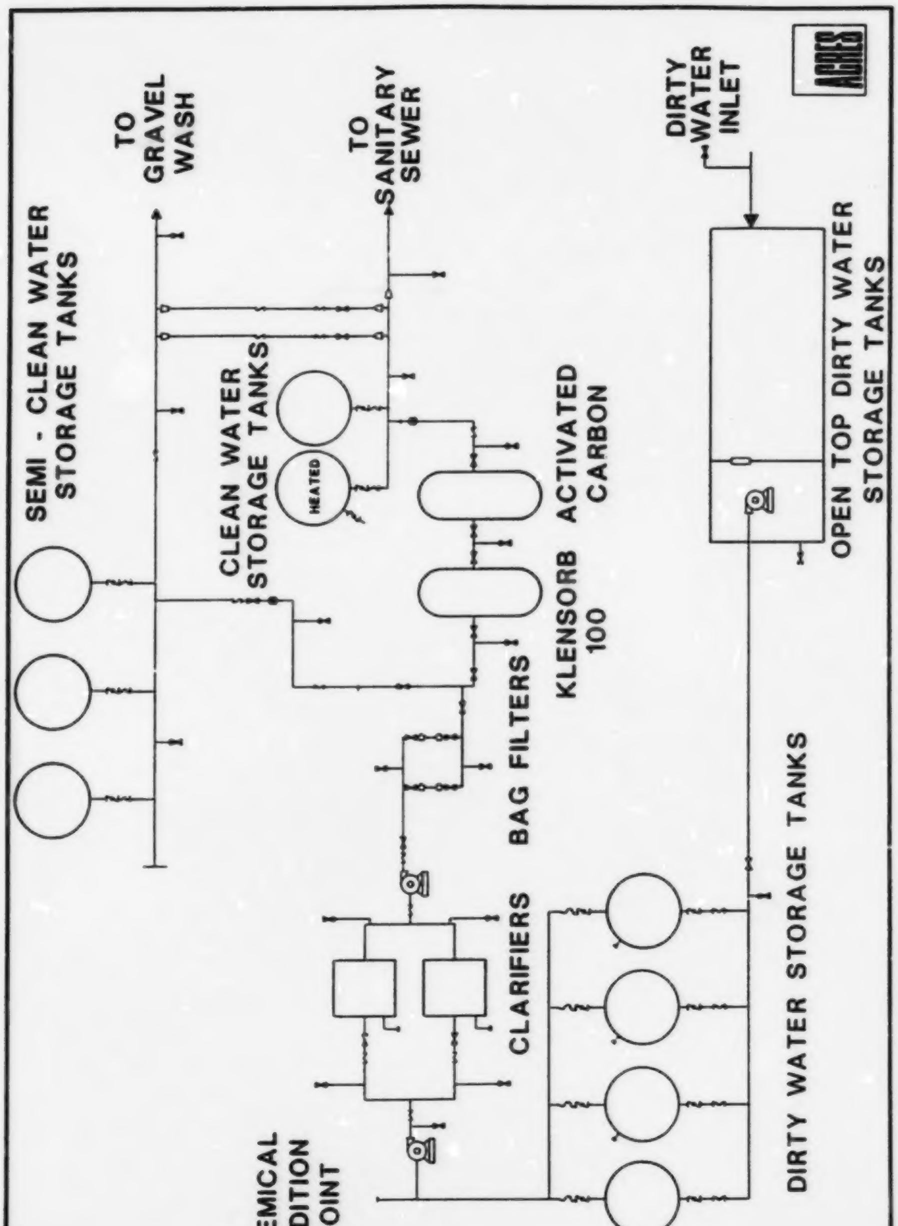
The Fall 1991 program of pilot work on the Canada Creosote, Calgary project was completed successfully on time, on budget and fulfilled all its major objectives. Information gathered will be used in on-going risk assessment and other studies and investigations leading towards an appropriate strategy for remediation of the site.


EXISTING BERM
PILOT COFFERDAM
SHEET PILE CELL
CONCRETE CELL
OFFICES
BOW TRAIL
GRAVEL WASHING PLANT
BOW RIVER
WATER TREATMENT PLANT
ACRES
N
0 3 6 9 12 15m

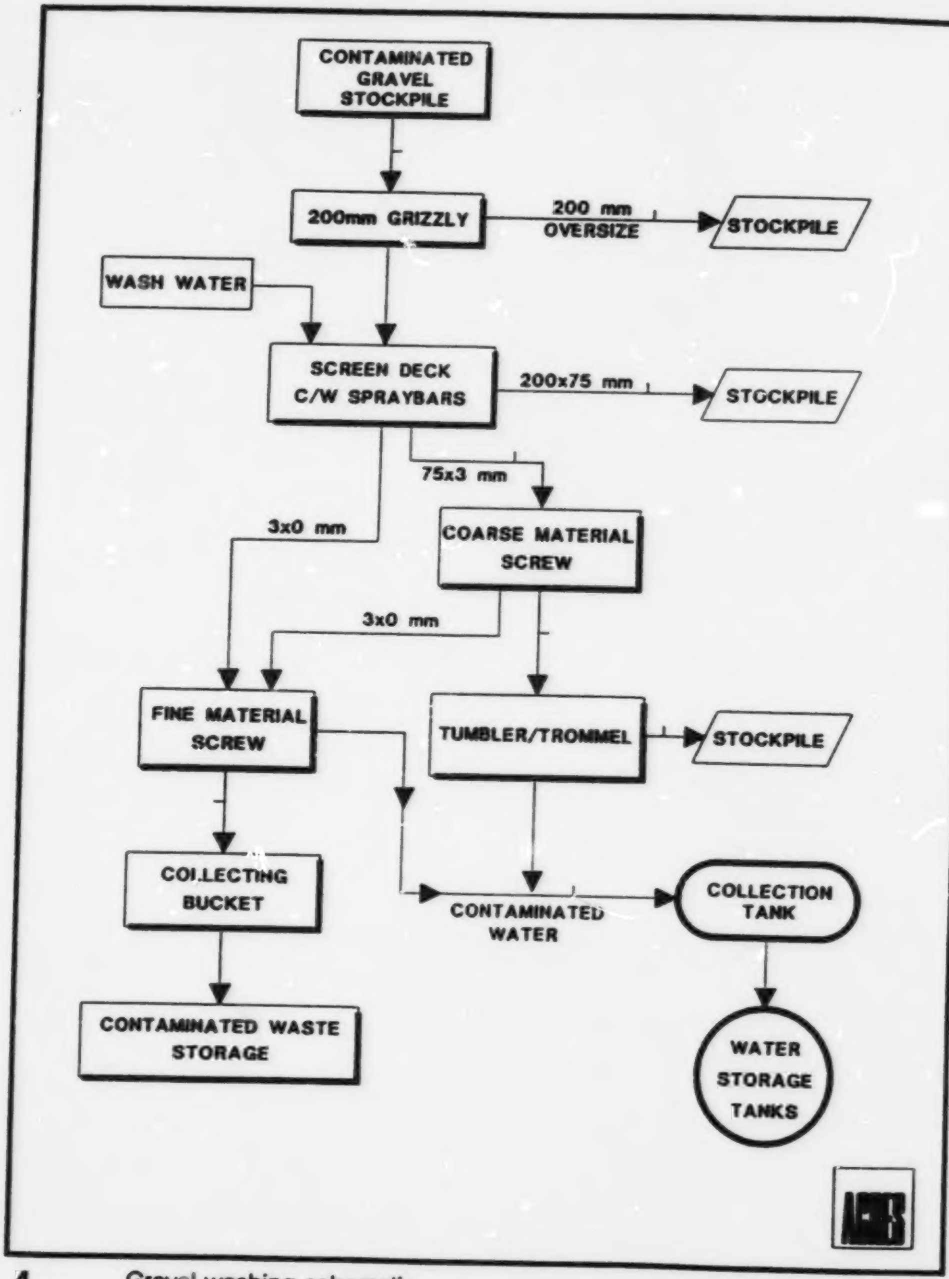
1 Overall site plan.


CONCRETE CELL
STEEL SHEET PILE CELL
EARTHFILL BERM
0 1 2 3 4m
WATER
IN-SITU SLURRY CUT-OFF
CONTAMINATED RIVER GRAVELS (EXISTING)
PIT RUN GRAVEL
BEDROCK
ACRES

2 Alternative cofferdam construction methods.


SEMI - CLEAN WATER STORAGE TANKS
TO GRAVEL WASH
TO SANITARY SEWER
CLEAN WATER STORAGE TANKS
HEATED
KLENSORB 100
ACTIVATED CARBON
BAG FILTERS
CLARIFIERS
CHEMICAL ADDITION POINT
DIRTY WATER STORAGE TANKS
OPEN TOP DIRTY WATER STORAGE TANKS
DIRTY WATER INLET
ACRES

3 Water treatment pilot.


CONTAMINATED GRAVEL STOCKPILE
200mm GRIZZLY
200 mm OVERSIZE
STOCKPILE
WASH WATER
SCREEN DECK C/W SPRAYBARS
200x75 mm
STOCKPILE
75x3 mm
3x0 mm
COARSE MATERIAL SCREW
3x0 mm
FINE MATERIAL SCREW
TUMBLER/TROMMEL
STOCKPILE
COLLECTING BUCKET
CONTAMINATED WATER
COLLECTION TANK
CONTAMINATED WASTE STORAGE
WATER STORAGE TANKS

4 Gravel washing schematic.

BIOGRAPHICAL SKETCH

Colin Beresford, P.Eng. is a project manager in the Calgary office of Acres International Limited. He has an M.Sc. in maritime engineering from Liverpool University, England and twenty-six years experience in the design, construction and project management of a wide variety of major projects world wide. He is currently project manager for the remediation of the Canada Creosote site in Calgary.

15.0

LEACHATE CHARACTERISTICS OF GASOLINE CONTAMINATED SOIL

BY

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Paper unavailable at time of printing.
Texte non reçu au moment de mettre sous presse.

EVALUATION OF SOIL WASHING AND BIOSLURRY REACTOR TREATMENTS
FOR
SOIL CONTAMINATED WITH PCBs AND HEAVY METALS

by

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Hazardous Waste Section
Toxics, Contaminants and Waste Management Branch
Environmental Protection
Environment Canada
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and

Louise Steward

New Brunswick Department of the Environment

March 1992

INTRODUCTION

Soil contaminated with PCBs and heavy metals was identified at the site of a former salvage operation on the New Brunswick Department of Transportation (NBDOT) property in Saint John, New Brunswick. The historical problems associated with the remediation of soils contaminated with this combination of materials required the implementation and evaluation of innovative remediation options.

To that end, in 1991, the New Brunswick Department of Environment (NBDOE) issued a contract to Washburn and Gillis Associates Ltd. (in association with Keystone Environmental Resources Ltd.) to conduct a study to evaluate soil washing and bioslurry reactor techniques for soil contaminated with PCBs and heavy metals. This project was jointly funded by Environment Canada and NBDOE under the Development and Demonstration of Site Remediation Technology (DESRT) component of the National Contaminated Site Remediation Program (NCSRP).

The objective of the study was to determine the feasibility of soil washing and bioslurry reactor techniques to remove PCBs and heavy metals from the soils at the NBDOT site. The results of the study will be used to determine the costs and feasibility of a full scale site clean-up.

An integral part of the study design was the evaluation of two distinct approaches for the demonstration of the remediation techniques. The first approach involved the removal of heavy metals by soil washing followed by bioslurry treatment of the residual PCB contaminated soil. The second approach consisted of the removal of PCBs by solvent extraction to facilitate eventual treatment/disposal of the metal contaminated soil.

To date, the soil washing and bioslurry components of the study have been completed and the results of the soil washing portion have undergone preliminary evaluation. The bioslurry results are not yet finalized.

This paper is based on the work conducted and reported by Washburn & Gillis Associates Ltd. and Keystone Environmental Resources Ltd., and documents the preliminary findings of the soil washing treatability study. The report also examines the sampling and experimental programs, and discusses on the results obtained to date.

SAMPLING AND CHARACTERIZATION

Previous site investigations had indicated that the site was contaminated by PCBs and heavy metals. Cadmium (Cd), copper (Cu), lead (Pb), zinc (Zn) and PCBs were present in concentrations exceeding acceptable limits, as outlined in the CCME Interim Environmental Quality Criteria for Contaminated Sites. While contamination was found to a depth of approximately one metre, it appeared to be fairly localized.

Prior to the initiation of the treatability study, 4 Kg. soil samples were collected from within a one metre sampling grid at the site. The soil samples were saturated, dried, combined and subjected to a series of mixing, splitting and homogenization procedures to provide representative samples for use in the study.

Following the splitting process, one half of the total sample was forwarded to Environment Canada's River Road Environmental Technology Centre (RRETC) in Ottawa for parallel studies.

A 400 g subsample of the original 4.0 Kg sample of soil was collected and submitted for analysis of cyanide and sulphur as these components, if present in sufficient concentrations, could potentially lead to hazardous emissions during the treatability studies. The subsample was also analyzed for aluminum (Al), calcium (Ca), iron (Fe), magnesium (Mg) and manganese (Mn) to provide additional information with respect to required extractant dose (e.g. potential reactions with extractants). Concentrations of anions (e.g. phosphate, sulphate and sulphite) were determined to identify potential metal carriers.

Soil characterization results are found in the table below.

Table 1 Soil Characterization Results

Parameter	Concentration (mg/Kg)
PCB	484.0
Cadmium	11.7
Copper	11,300.0
Lead	13,600.0
Zinc	3,190.0

EXPERIMENTAL METHODOLOGY

The soil washing treatability study was conducted in two phases. In Phase I the target constituents for removal were heavy metals (Cd, Cu, Pb, and Zn). Phase II focused on the removal of PCBs.

Experiments conducted in Phase I consisted of a series of screening tests (Task 1) to identify the most effective extractant for the removal of metals, and a second series of tests (Task 2) to optimize the experimental conditions using the best extractant identified in Task 1. The tests were performed using a jar test unit (Phipps & Bird) (see Figure 1). The maximum impeller speed maintained during the metal extraction tests was 250 rpm.

Phase I, Task 1

A total of five tests were performed during Phase I, Task 1. The specifics of these tests are outlined below:

	TEST #	EXTRACTANT/CONDITIONS
*	#I-1-1:	Hot water at 40°C. Water obtained from on-site tap.
*	#I-1-2:	Hydrochloric acid (HCl). Slurry maintained at pH 2.
*	#I-1-3:	Verseen Tetraammonium EDTA (Verseen Tetra by Dow International). Used at a concentration of 10% by weight.
*	#I-1-4:	Kalex liquid (Kalex by Dow International). Used at a concentration of 10% by weight (in water).
*	#I-1-5:	Series test. Consisted of sequential extractions involving hot water, HCl and Verseen Tetra.

All of the above screening tests were conducted using slurry with a soil to liquid (water and/or extractant) ratio of 1:3. With the exception of Test #I-1-5, the extraction times for all tests was 2 hours. In Test #I-1-5, the soil was sequentially extracted with hot water, HCl and Verseen Tetra. The extraction time for each extractant was 30 minutes.

Upon completion of the tests, samples of the slurry were collected and analyzed for percent solid, soil pH, Cd, Cu, Pb, Zn and PCBs.

Based on the analytical results and observations obtained during the tests, Kalex liquid was selected as the most effective extraction for the optimization tests.

Phase I, Task 2

A total of six tests were performed during Task 2. The purpose of this task was to determine optimum conditions for the removal of heavy metals from soil by the selected extractant. The conditions for each of these tests are outlined below.

TEST #	EXTRACTANT/CONDITIONS
#I-2-1:	Soil extracted in two cycles of two hours each using 10% Kalex liquid.
#I-2-2:	Soil extracted for four hours using 10% Kalex liquid.
#I-2-3:	Soil extracted for four hours using 20% Kalex liquid.
#I-2-4:	Soil extracted for eight hours using 10% Kalex liquid.
#I-2-5:	Soil extracted with 10 % Verseen Tetra for two hours, then rinsed and extracted with HCl for two hours.
#I-2-6:	Soil extracted for 24 hours using 10% Kalex liquid with intermittent mixing.

Tests #I-2-1, #I-2-3, #I-2-5 and #I-2-6 were designed based on preliminary results obtained from the metal screening tests. Tests #I-2-2, #I-2-4 and #I-2-6 were carried out to determine the effect of extraction time.

Upon completion of the tests, samples of the slurry were collected and analyzed for percent solid, soil pH, Cd, Cu, Pb, Zn and PCBs.

Phase II - PCB Removal

Phase II was also divided into two tasks. Task 1 consisted of a series of screening tests to identify the most effective surfactant for the removal of PCBs while Task 2 consisted of a series of tests to evaluate the effects of increased wash cycle and extraction time on the process performance. The tests were performed using a Denver soil washing unit (jar tests - see Figure 1). The reagent which yielded the best results was selected and used in Task 2.

Phase II, Task 1

The PCB screening tests were conducted using 0.25% (by weight) of each of the following surfactants:

- Test #II-1-1: Olin 4750
- Test #II-1-2: Redicote E-11
- Test #II-1-3: Witconate 1223L
- Test #II-1-4: Tween 80.

These surfactants are commercially available organic surface active agents. In all tests the slurry was prepared at a soil to liquid ratio of 1:3. Soil was extracted once for ten minutes. Following the extraction, the washed soil was rinsed with an alkaline solution followed by a tap water rinse. Settling time was 15 minutes for each component of the tests.

Upon completion of the tests, samples of the washed soil were collected and analyzed for percent solid, soil pH, Cd, Cu, Pb, Zn and PCBs.

Phase II, Task 2

Redicote E-11 yielded the best results with respect to PCB removal, and was chosen as the surfactant for the second series of tests. In Task 2, a 0.5% solution of Redicote E-11 was used in the following experiments tests.

TEST #	CONDITIONS		
	Wash Time	#Cycles	Rinse Solution
#II-2-1:	10 minutes	1	Alkaline - water
#II-2-2:*	10 minutes	1	Alkaline - water
#II-2-3:	30 minutes	1	Alkaline - water.
#II-2-4:	45 minutes	1	Alkaline - water.

* The sample used for this test was a subsample of that used in Test #II-2-1, and was therefore actually subjected to 2 cycles.

Upon completion of the tests, samples of the slurry were collected and analyzed for percent solids, soil pH, Cd, Cu, Pb, Zn and PCBs.

Soil Washing Treatability Study - Results and Discussions

Metals Removal

The analytical results found in Table 2 indicate that, among the four extractants tested during the metal screening evaluation, hot water was effective only in removing lead. Hydrochloric acid (HCl) was found to be effective in removing most of the contaminants of concern. Removal rates for metals using HCl as the extractant ranged from 32% for copper to 63% for lead. Metals removal using Verseen Tetra ranged from 25% for zinc to 63% for lead. Metal removal using Kalex liquid removal ranged from 6% for zinc to 75% for lead. Results for the combination run, using hot water, HCl and Verseen tetra indicated essentially no removal of copper, with removal for Cd, Pb and zinc of 50%, 12% and 25% respectively. These results are depicted grapically in Figure 2.

As previously stated the use of hot water alone did not result in the removal of any constituents of interest except lead. A mineralogical analysis of the soil conducted by Canmet for the parallel studies directed by the RRETC, indicated that a majority of the metals of concern at the site occurred in metallic form (Pb and Cu at approximately 95%). With hot water alone, physical separation through vigorous agitation and flotation was probably

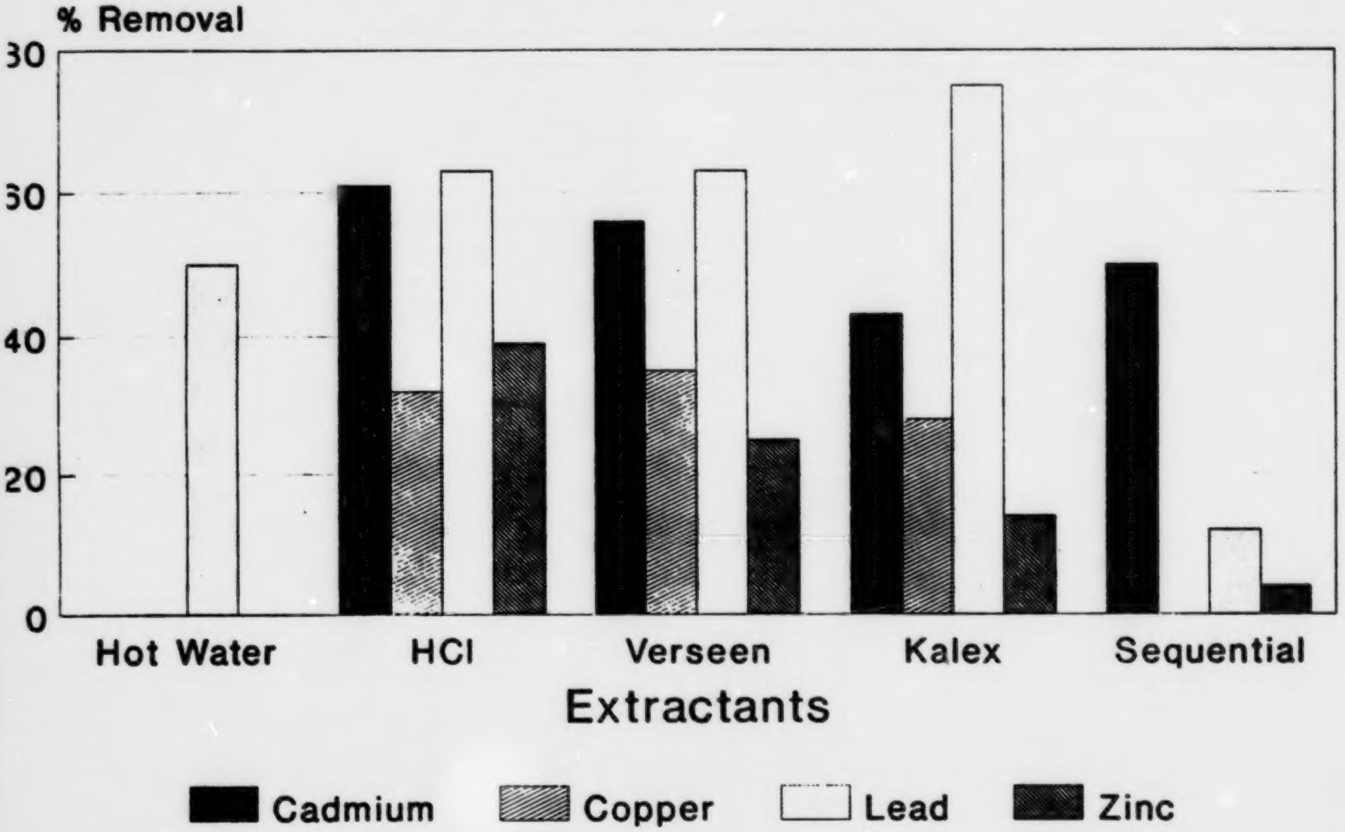
Table 2. Phase I, Task 1
Metal Screening

Test #	Reagent	Percent Removal (%)			
		Cd	Cu	Pb	Zn
I-1-1	Hot water	0	0	50	0
I-1-2	HCl	61	32	63	35
I-1-3	Verseen Tetra	56	35	63	25
I-1-4	Kalex	43	28	75	6
I-1-5	Sequential	50	0	12	25

Wash time: 2 hours

One cycle

Figure 2. Phase I, Task 1
% Removal Metals



the most important mechanism for the removal of metals from the soil, as opposed to chemical separation.

Compared to the results obtained from the use of individual extractants, it appears that sequential extractions used in Test #I-1-5 did not enhance the metal removal. This may be attributed to the short extraction time (30 minutes per extractant) in this experiment. As a result, a minimum of two hours was selected as the extraction time in Phase I, Task 2.

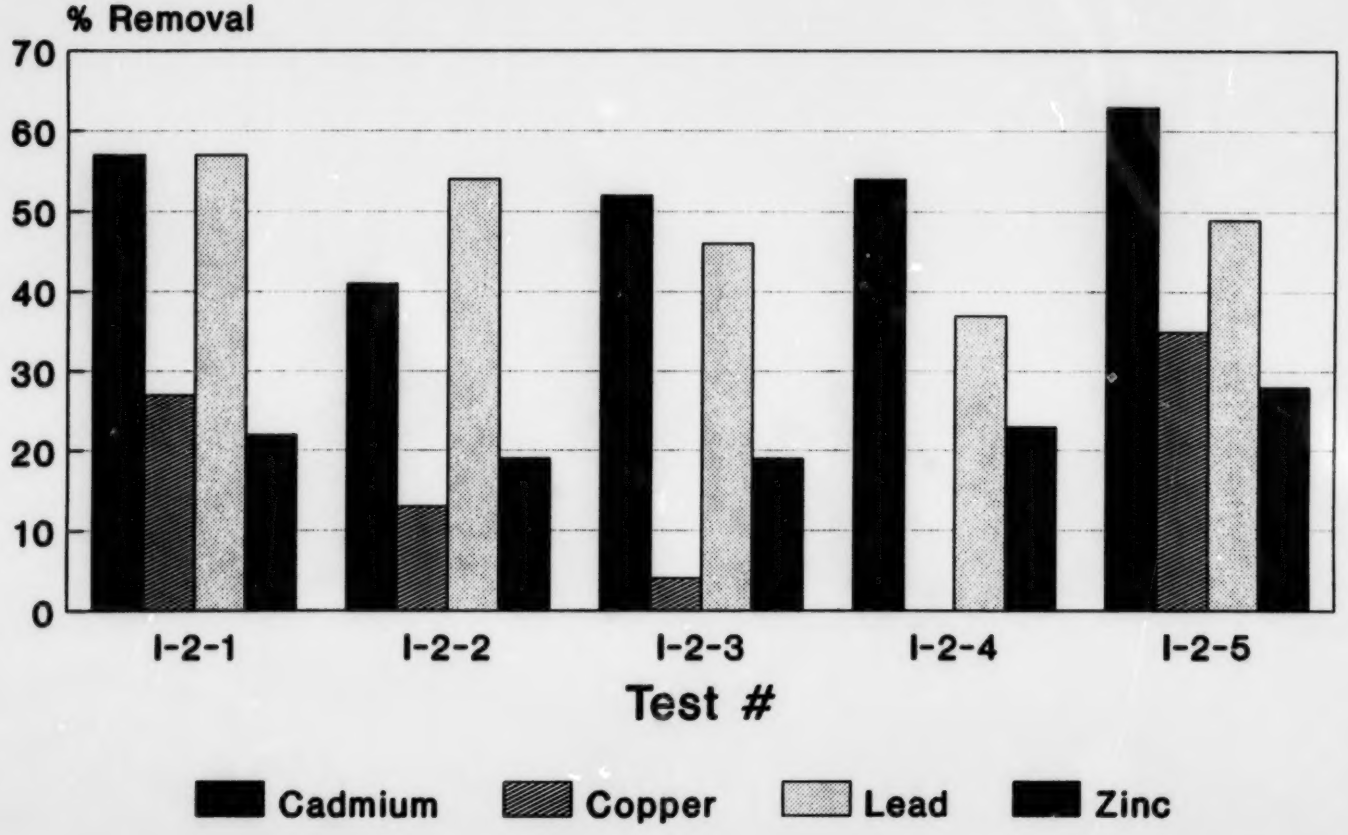
Hydrochloric acid (HCl) appeared to be the most effective extractant for metal removal. However, due to certain operational constraints such as fume emission, HCl was not used as a primary extractant during Phase I, Task 2. It was however, used as a secondary extractant following an initial soil treatment with Verseen Tetra to avoid the fuming problem (the lower concentration of metals in pretreated soil results in a lower dissolution effect from HCl). The use of 10% Verseen Tetra resulted in metals removal comparable to those obtained with HCl during Phase I, Task 1 testing. This is attributed to the strong chelating effect of the tetraammonium salt. Due to the limited quantity of Verseen tetra available for this study it was only used in conjunction with HCl during Phase I, Task II.

Visual observations of the soil during washing indicated that Kalex liquid provided the best wetting characteristics, therefore allowing more contact between surfactant and contaminant. As the use of HCl presented operational constraints, and only limited quantities of Verseen Tetra were available, Kalex liquid, which exhibited only slightly less metal removal capability than the Verseen tetra, was the primary extractant for the optimization tests conducted during Phase I, Task 2.

Test #I-2-1 was designed to evaluate the effect of a double wash cycle on the process performance. An additional wash cycle resulted in an improved removal of Cd and Zn. Cadmium and zinc removal in Test #I-1-4 (a single wash cycle) was 43% and 6% respectively while Test #I-2-1 (a double wash cycle) resulted in the removal of 57% and 22% cadmium and zinc respectively. The increased removal may be attributed to the enhanced surface reaction rate and interfacial mass transfer imparted by constant contact with a fresh extractant. Copper removal remained essentially the same for both tests, while lead removals were lower. The analytical results for these tests are depicted in Figure 3.

Tests #I-2-2, I-2-4 and I-2-6 were designed to evaluate the effect of increased extraction time on the process performance. The results were compared to those obtained during Test #I-1-4 where soil was extracted for two hours under identical experimental conditions. Some beneficial effects were noted as a result of prolonged extraction time (see Figure 3). Removal of cadmium and

Figure 3. Phase I, Task 2
Metal Removal Optimization



Various Experimental Conditions

zinc increased with an increase in extraction time. Removal of copper remained essentially the same, while the removal of lead initially decreased to 37% after an 8-hour extraction, but increased to 54% after a 24-hour extraction. Data which deviated from the trend seemed to be anomalous and could be the result of the sampling or analytical variability which is often observed with soil samples.

PCB Removal

Table 3 shows that Redicote E-11 resulted in the greatest removal of PCBs from the soil, with 46% removal. Olin 4750 and Witconate 1223L removed 36% and 33% of PCBs respectively. Tween 80 removed only 8% of the PCBs from the soil. Based on these results Redicote E-11 was selected for use in the optimization tests (Phase II, Task 2).

A comparison of the results for Test #II-1-2 (0.25% solution of Redicote) and Test #II-2-1(0.5% solution of Redicote) indicates that doubling the surfactant concentration has improved PCB removal from 46% to 52% (see Figures 4 and 5).

Results obtained from Tests #II-2-1, #II-2-3 and #II-2-4 were used to evaluate the effect of prolonged wash time on the process performance. In general, no beneficial effect was obtained from extending the wash time (see Figure 5). Removal of the majority of the constituents from the soil appeared to take place during the

Table 3. Phase II, Task 1
PCB Screening

Test #	Reagent *	Percent Removal (%)				
		PCB	Cd	Cu	Pb	Zn
II-1-1	Olin 4750	36	47	25	54	28
II-1-2	Redicote	46	52	47	42	41
II-1-3	Witconate	33	47	46	21	32
II-1-4	Tween 80	8	47	16	0	39

* all reagents at (0.25%)

Wash time: 10 min

One cycle

Figure 4. Phase II, Task 1

% Removal PCBs

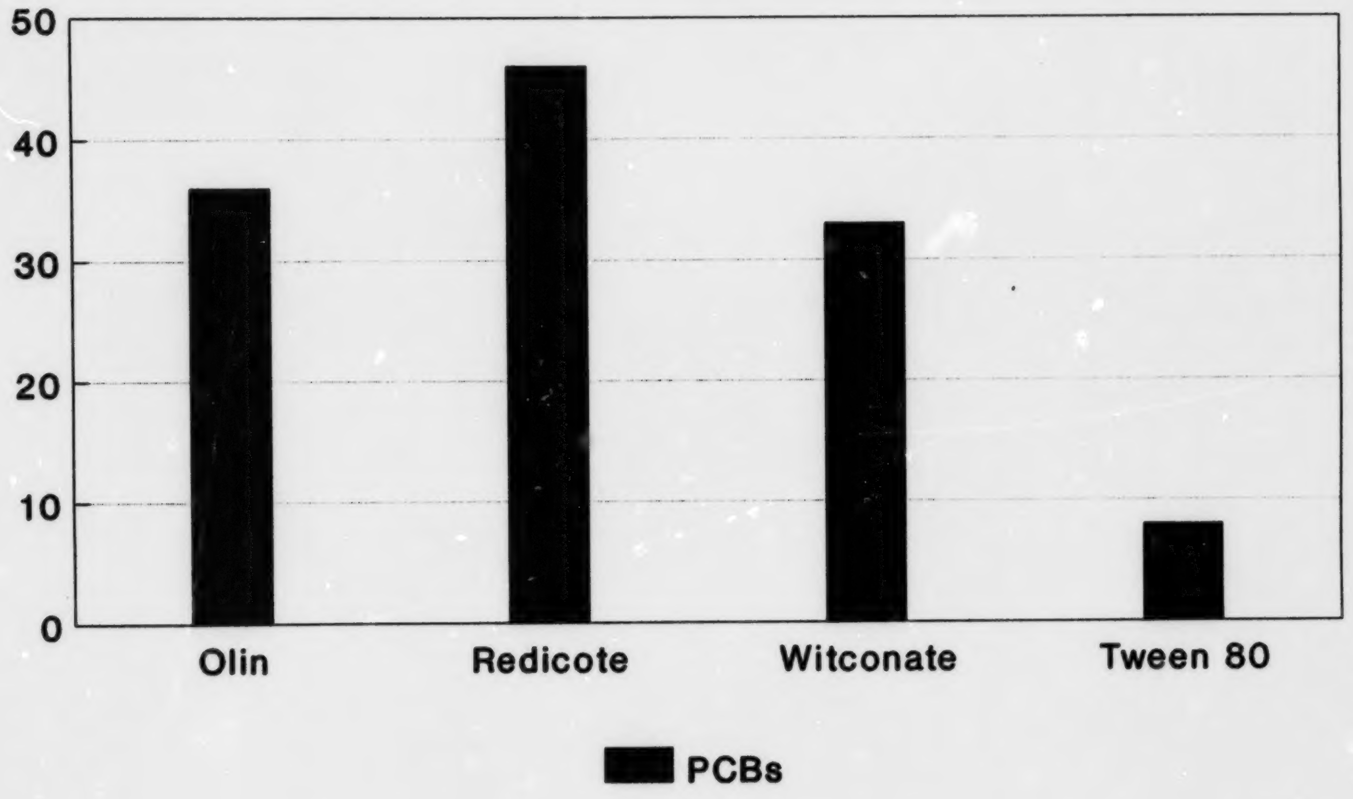


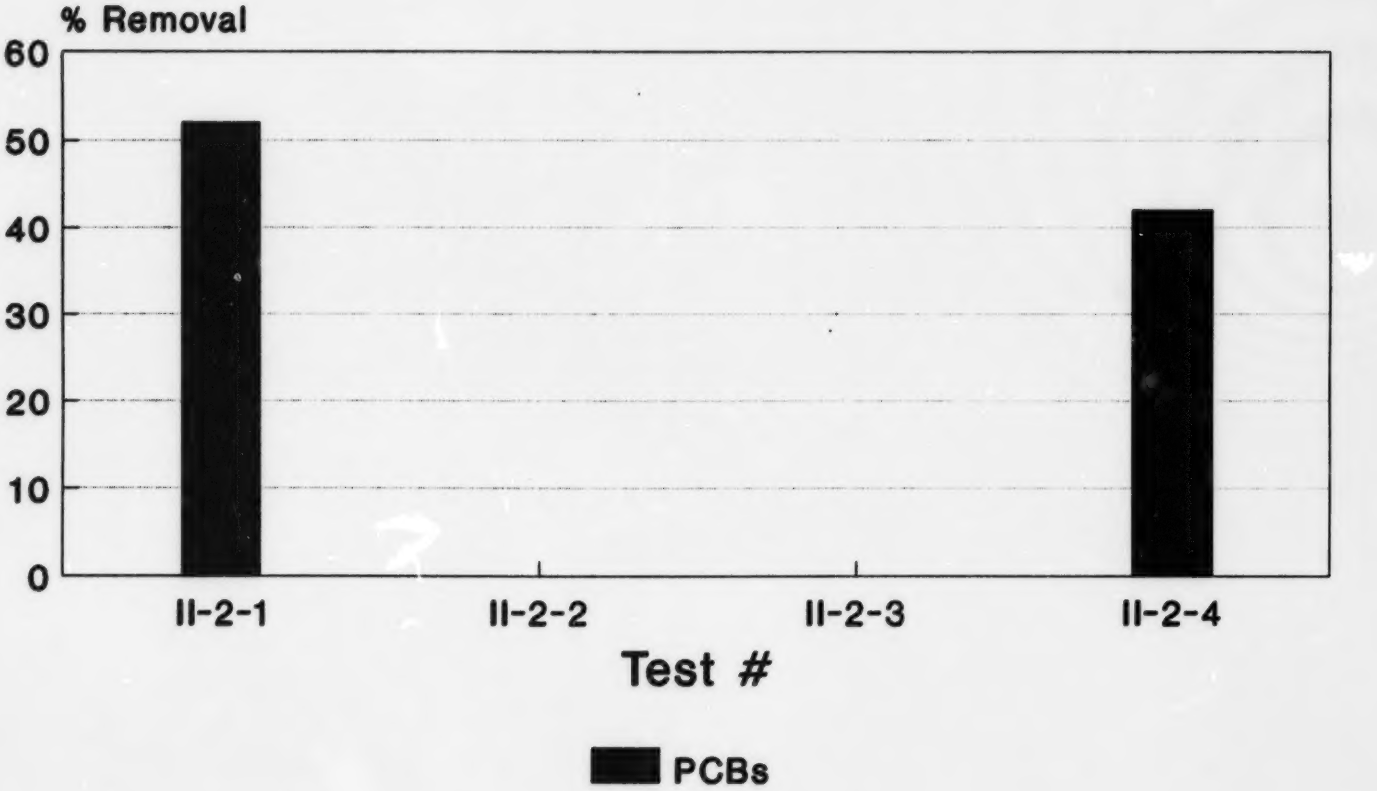
Table 4. Phase II, Task 2
PCB Removal Optimization

Test #	Reagent *	Wash Time**	No. of Cycles	Percent Removal (%) PCB
II-2-1	Redicote	10	1	52
II-2-2	Redicote	10	2	0
II-2-3	Redicote	30	1	0
II-2-4	Redicote	45	1	42

* all reagents at 0.5%

** time in minutes

Figure 5. Phase II, Task 2
PCB Removal Optimization



initial 10 minutes of operation provided that proper experimental conditions were maintained and that sufficient amounts of surfactant and agitation intensity were applied.

SUMMARY AND CONCLUSIONS

The findings of the soil washing treatability study can be summarized as follows.

- Results of the initial soil characterization revealed that the soil samples used in the treatability study contained considerably higher concentrations of lead and PCBs than previously reported by Washburn & Gillis in 1989. The maximum PCB and lead concentrations identified were 22,800 mg/Kg and 3400 mg/Kg respectively.

- Extractants tested for metal removal were hot water, HCl solution (pH 2), Verseen Tetraammonium EDTA, and Kalex liquid. HCl was the most effective based on overall process removals. HCl appears to be relatively effective in removing PCBs. Operational constraints prohibited use of HCl directly on raw soil.

- A minimum 2-hour extraction time was required for effective removal of the metals from the soil sample. Prolonged extraction times slightly improved process performance.

- A double wash cycle slightly improved metal removal. This is attributed to an enhanced surface reaction rate and interfacial mass transfer as a result of constant contact with fresh extractant.

- Lower than anticipated metals removals were achieved. This can be attributed to the fact that many of the metals were present in elemental form.

- Redicote E-11 was the most effective of the surfactants tested for PCB removal. In addition, Redicote E-11 was also effective in removing the metals of concern from the soil.

- Although an increase in extractant or surfactant concentrations resulted in a higher percent removal of some of the constituents of concern, the magnitude of the improvement does not warrant further evaluation.

- For PCB removal with surfactants, no enhanced effect was obtained from prolonged washing cycles. Removal of the majority of the metals of concern appears to have taken place during the initial 10 to 20 minutes of operation.

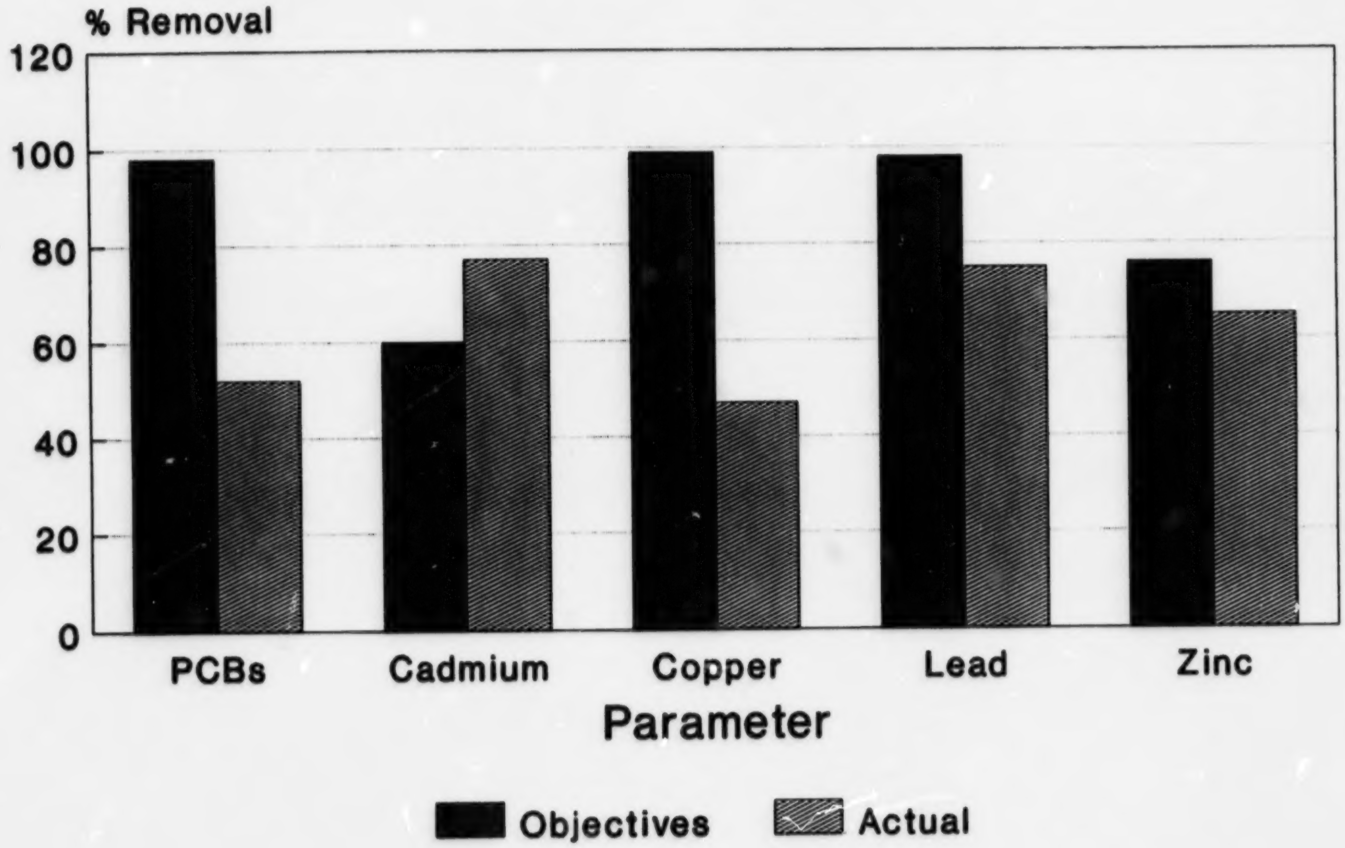
Table 5 compares the results obtained from the soil washing treatability study with the study treatment objectives. Desired removal rates ranged from 60% for cadmium to 99% for copper.

Table 5. Removal Objectives vs. Actual removal

Parameter	Desired % Removal	Actual Removal*
PCB	98	52
Cadmium	60	77
Copper	99	47
Lead	98	75
Zinc	76	65

*Maximum Removal Obtained

Figure 6.
Removal Objectives vs. Actual Removal



Actual removal rates ranged from 47% for copper to 77% for cadmium. The removal rates for the other constituents were considerably lower than the original objectives.

The data indicates that soil washing is effective in removing a large percentage of metals from contaminated soil. For all but one constituent, the percent removal obtained was greater than 50%. However, even with the percent removal obtained, soil contamination levels would still exceed acceptable criteria.

Comparable results were obtained in a parallel study conducted by RRETC. Although they used different extractants (nitric acid for metals) and different operating conditions removal rates were in the same order of magnitude as those for this study.

The lower than desired removal rates is attributed to the presence of elemental metals in the site soil.

Table 1. Soil Characterization Results

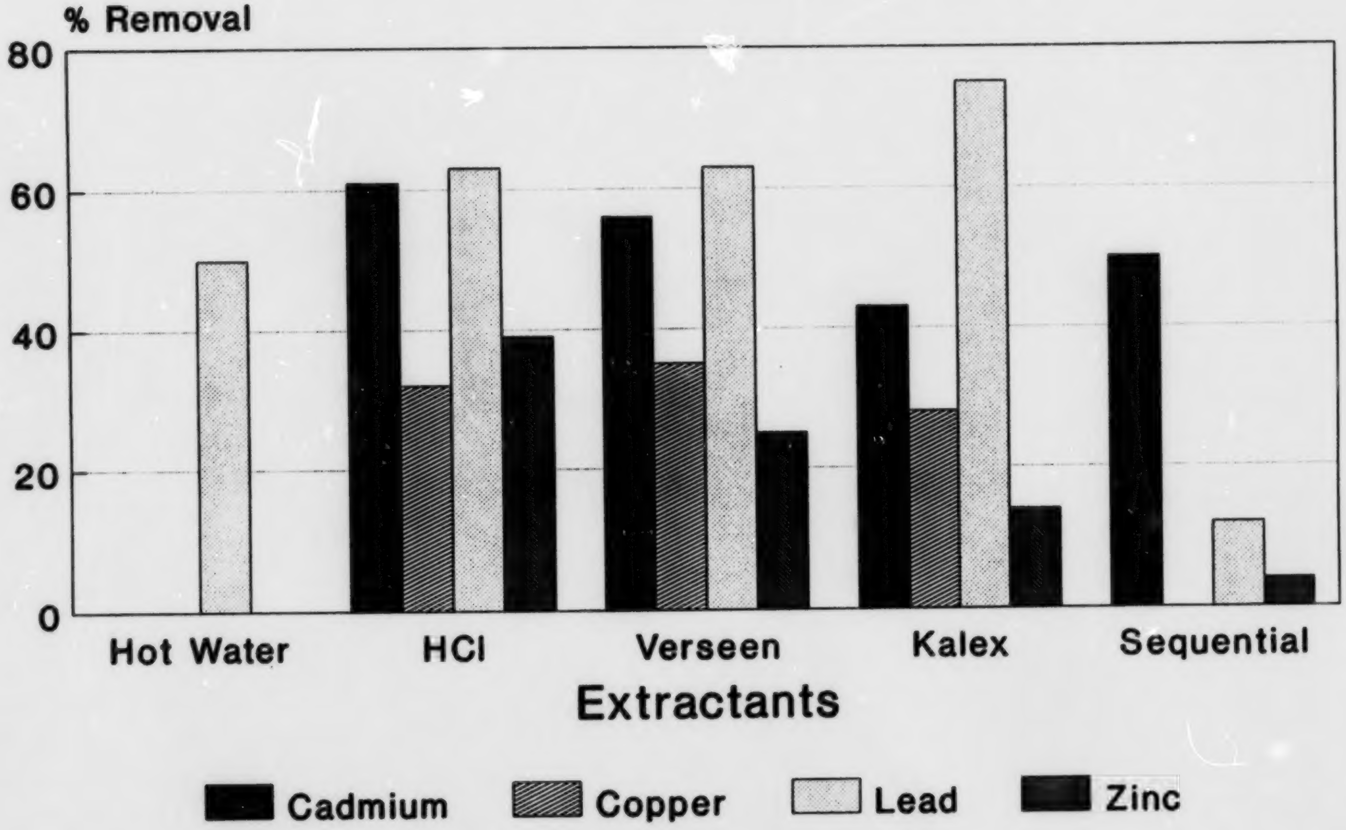
Parameters	Concentration (mg/Kg)
PCB	484
Cadmium	11.7
Copper	11,300
Lead	13,600
Zinc	3190

Table 5. Removal Objectives vs. Actual removal

Parameter	Desired % Removal	Actual Removal*
PCB	98	52
Cadmium	60	77
Copper	99	47
Lead	98	75
Zinc	76	65

*Maximum Removal Obtained

Figure 2. Phase I, Task 1
% Removal Metals



16A.1

Land Treatment of Alberta Oilfield Wastes and Reclamation of Treatment Sites

by

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A full account of this project, including a summary report entitled, "Disposal of oilfield wastes by land treatment in Alberta: Summary on feasibility, environmental risk assessments and future land use" are available from the Canadian Petroleum Association. Copies may be obtained from Pallister Resource Management Ltd., 105, 4116 - 64th Avenue N.E., Calgary, Alberta T2C 2B3. Major funding for this research was provided by the Canadian Petroleum Association, Environmental Research Advisory Council, and Environment Canada.

16A-2

Land Treatment of Alberta Oilfield Wastes and Reclamation of Treatment Sites

A program was initiated in 1982 and concluded in 1989 to determine the feasibility of using the land treatment/biodegradation method for the disposal of select oil field production facility wastes in Alberta. Emphasis was placed on determining rates of degradation of hydrocarbon wastes under different soil and climatic conditions, methods to enhance biodegradation, effects on surface and groundwaters, uptake of organic compounds by plants, and reclamation of land treatment sites.

Demonstration plots were established at the following Alberta locations: Lloydminster, Grande Prairie, Drayton Valley, and Brooks. Oily wastes were applied once per year for two to four years at these sites. At Lloydminster heavy oil wastes such as tank bottoms and slop oil were applied and at the other three sites untreatable residuals from reclaiming plants were used for land treatment. Four levels of sludges were applied at each site but amounts added varied among sites and between years depending upon materials available and the desired adjustments of oil levels in the soil. At each site two levels of fertilization and two frequencies of cultivation were also included as treatments. All plots were limed to above pH 7 to reduce the leaching of heavy metals. Soil oil (hydrocarbon) contents, soil inorganic chemistry, and groundwater and surface water quality were monitored periodically at all sites. After oily waste applications had ceased, all sites were planted to field crops and plant yield measured. Detailed assessments of crop production, groundwater quality, crop quality, and reclamation procedures were conducted at the Lloydminster site.

None of the parameters measured, including oil degradation rates, appeared to be influenced by either cultivation frequency or fertilization rates. Both of these factors may influence oil degradation rates but either both rates used were in the optimum range or, more probably, variability under field conditions precluded the detection of treatment effects.

The oil contents of the soils ranged from 0.8 to 13.5% over the course of the study, but were generally maintained between 3 and 6% and degradation occurred relatively rapidly at all oil concentrations. It was assumed that microbial decomposition was the major agent responsible for the disappearance of hydrocarbons although it was recognized that volatilization of low molecular weight compounds occurred, especially immediately after sludge applications. During the first year, 70% of the oil disappeared at the Grande Prairie site, 50% at Drayton Valley, 23% at Brooks, and 14% at Lloydminster. The large differences in decomposition (plus volatilization and nonbiological degradation) rates may have been due, at least in part, to the heavier nature of the oil at the latter two sites. Additional oil applications were made to all sites except Brooks and after yearly applications were made for 3 years, 71% (130,000 kg ha^{-1}) of oil had degraded at Grande Prairie, 71% (216,000 kg ha^{-1}) at Drayton Valley, and 49% (179,000 kg ha^{-1}) at Lloydminster. It appeared that the loading potentials of the soils were very high as similar rates of degradation could be found with soil oil contents as high as 13.5%. Only at Lloydminster where the least rapidly degraded oil was applied, were the studies continued for the full 8 years and at the end of that period, 4 years after the last application of oil, 73% (196,000 kg ha^{-1}) of the oil had degraded (Fig. 1). In the final 3 years of the study, the average amounts of degradation (all treatments combined) were 15, 23, and 10% with a final soil oil content of 1.3%. Only in the last year did degradation rates diminish substantially.

Despite expectations to the contrary, there was not an accumulation of asphaltenes in the soil at Lloydminster but rather a steady decrease after the final oil application was made; specifically, asphaltenes in the soil decreased 14, 15, and 17% in each of the last 3 years (Fig. 2). The asphaltene content of the oil ranged from 19 to 23% in the same period with no obvious increase in heavy oil fraction with time (Fig. 3).

The oil was non-mobile at all four sites with only traces being detected below the cultivation zone (0-30 cm). Four years after the last application of oil a search was made in the upper 45 cm soil at Lloydminster for low molecular weight aromatic compounds which could represent future groundwater contaminants. None of the eight target compounds (dibenzothiophene, pyridine, carbazole, 2-methyl naphthalene, biphenyl, acridine, 4-methyl biphenol, and 9-ethyl fluorene) were detected in the soil at any depth.

The soil reaction remained above pH 7 for the entirety of the study at all four sites and thus the chance for heavy metal leaching was low. The addition of oil sludges to soils resulted in increased sodium adsorption ratios and electrical conductivities and increased concentrations of chlorides, sodium, and sulphates. Despite yearly applications of fertilizer, levels of inorganic nitrogen were very low in the soils treated with oily sludges.

At three sites, Grande Prairie, Drayton Valley and Brooks, hay or dryland pasture species were planted 2 years after the last oily sludge application. Growth of alfalfa and timothy at Grande Prairie was poor in the final year but improved marginally in the second growing season. At Drayton Valley growth of timothy and red fescue in the first year ranged from good to poor, with good growth occurring on plots with soil oil contents below 2.5% and poor growth occurring when oil contents exceeded 3.5%. Soil inorganic chemistry on plots where growth was good did not differ from that of untreated soil. The establishment of dryland pasture species at the Brooks site appeared to be restricted by a combination of oil stress and microenvironmental moisture conditions although good growth occurred in the second year on soil with relatively low oil contents.

A more detailed study of the relationship between plant growth and soil oil content was made at Lloydminster where barley was grown for four successive years and standard agricultural practices were used to rehabilitate the soil. When the first crop was planted one year after oil applications had ceased, soil oil contents ranged from 2.4 to 7.3% and barley growth ranged from excellent to nil thus presenting an excellent opportunity to make a quantitative determination of growth-limiting inhibition (Fig. 4).

Growth of barley in the second year was similar to that in the previous year but the results indicated that good growth was possible if oil contents were below 4%. In the 2.5-4% range, growth was highly variable and it appeared that salt concentrations were acting synergistically with oil-induced stress to inhibit growth. Measures were then taken to reduce both oil contents and salt concentrations in the root zone. These included deep ripping to shatter the clayey subsoil, heavy nitrogen fertilization to enhance microbial degradation of the hydrocarbons, and application of manure as a general soil amendment. These practices results in greatly improved barley biomass production in the third growing season (Fig. 5) with large decreases in electrical conductivity, chlorides and other ions as well as decreases in soil oil content. Application of manure resulted in a 2.4 fold growth increase although manure had no demonstrable effect on oil degradation or on the other chemical parameters measured.

As in some plots barley growth was still less than 1% of the growth on oil-free soil, the three remedial treatments were applied again after harvesting the third crop. This final attempt at reclamation of the oil treated soils was very successful as in the fourth year plant growth was virtually uniform regardless of oil treatment history and yields were similar to those on oil-free soil. For example, growth in a plot in which the yield was 29 g m^{-2} in the third year increased 592 g m^{-2} in fourth year, a 20-fold change. It was clearly shown barley could be grown in soils containing up to 4.5% of well-weathered oily wastes when slat concentrations were low ($\sim$2 dS m^{-1}).

In order to plan for future land uses of areas used for land treatment of oily wastes, the barley at Lloydminster was analyzed to determine if the plants had taken up toxic organic chemicals or heavy metals. A method was developed to extract organic compounds (acidic, basic, aliphatic, aromatic, and polar fractions) from plant material and was used to analyze green fresh-frozen and mature air-dry straw and grain. A larger number of compounds were detected in the fresh-frozen samples than in the air-dry samples. Nearly all the substances contained hydroxyl, aldehydic and/or carboxylic acid functional groups. Almost all the compounds were naturally occurring plant components or derived from natural products. It was unlikely that plant uptake from the soil was responsible for the presence of any of the compounds detected and there was a complete absence of toxic compounds that would render the crops unsuitable for animal or human consumption. Heavy metals were in similar concentrations in treated and untreated soils as well as in grain and straw grown in oily and oil-free soils.

Surface water runoff ponds initially became contaminated with mobile ions such as chloride but runoff water generally met Canadian Drinking Water Standards. Concentrations of chloride, nitrate, and sulphate gradually decreased at Lloydminster and at the end of the study the water met drinking water standards.

Groundwater at some sites became contaminated with chlorides and nitrates which originated from the sludges and fertilizer respectively. Detailed studies at Lloydminster showed that inorganic contamination decreased rapidly with depth and posed no major threat to water quality.

There did not appear to be any groundwater contamination with hydrocarbons at any site based upon total carbon analyses. At Lloydminster samples taken in 1988 from wells constructed of stainless steel and teflon indicated trace amounts (50 $\mu g\ L^{-1}$) of hydrocarbons had reached the groundwater. When the wells were resampled in 1989 no hydrocarbons were detected in the water indicating the organics from land treatment sites pose no threat to groundwater quality.

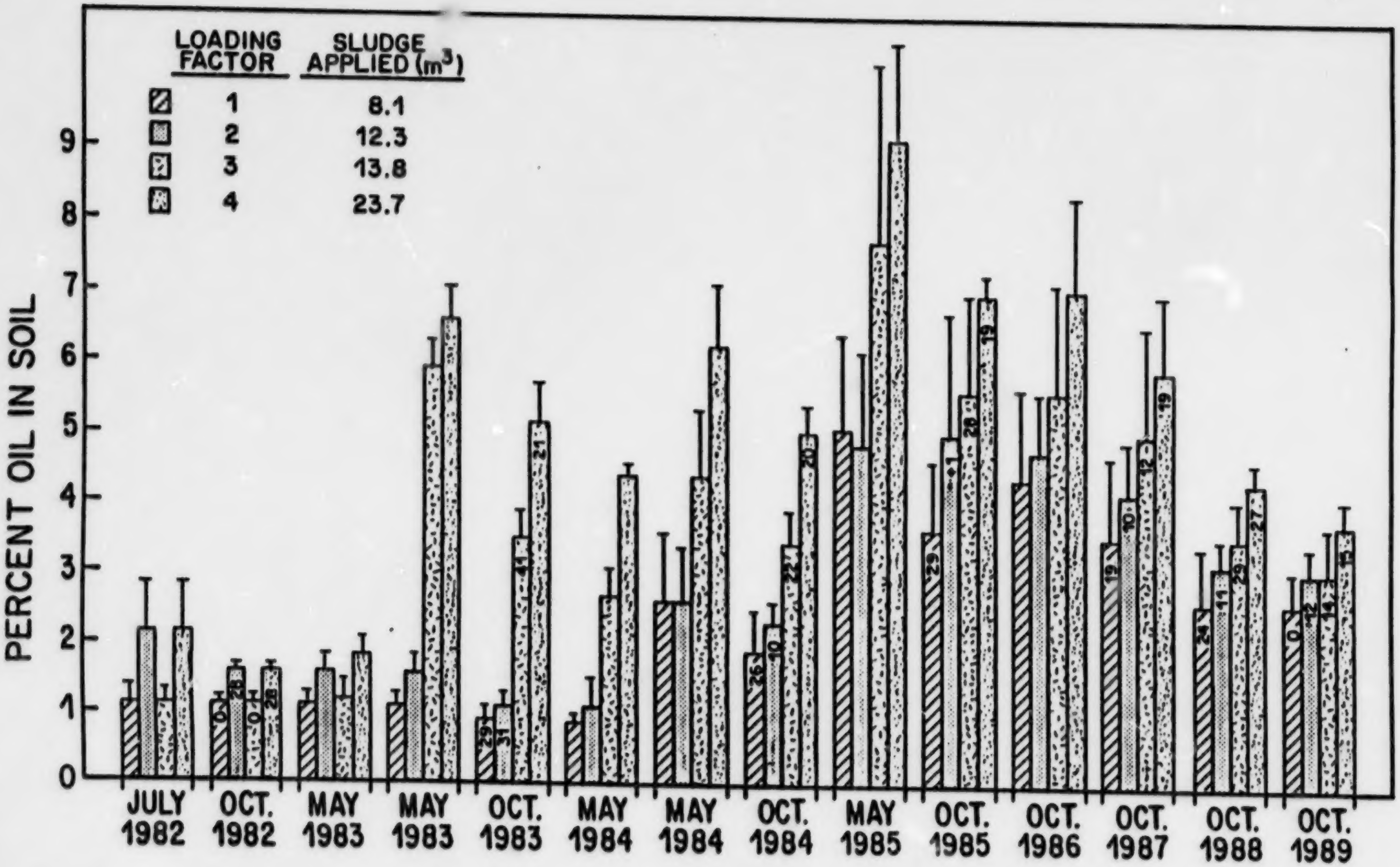

Figure 1. Oil content of soil at Lloydminster with oil added to all plots in 1982, 1984 and 1985 and to half the plots in 1983. Error bars are S.D., n = 4. Numbers in October bars are percent degradation from preceeding May (1982-1985) or October (1987-1989).

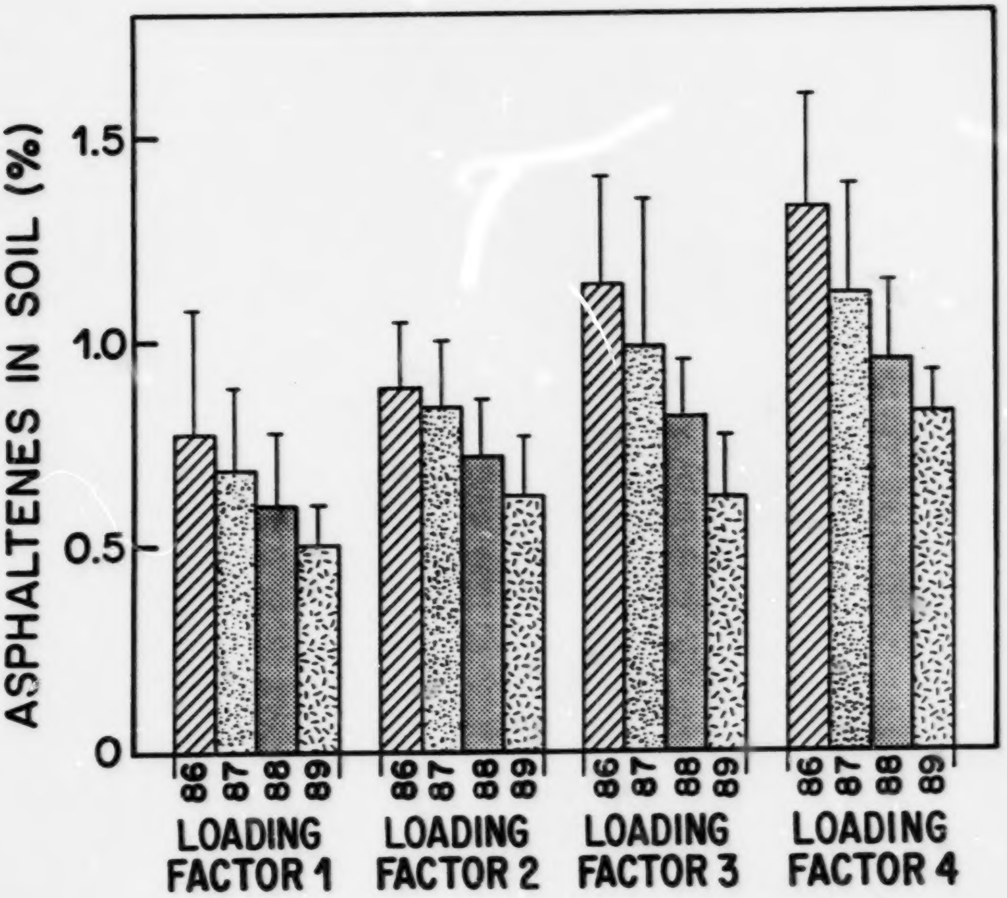

Figure 2. Asphaltene content in 1986 to 1989 of soil at Lloydminster which was treated with oily wastes 1982 to 1985 inclusively. Sludge loading factors are relative rates of oil application (1 = low, 4 = high). Error bars are S.D., n = 4.

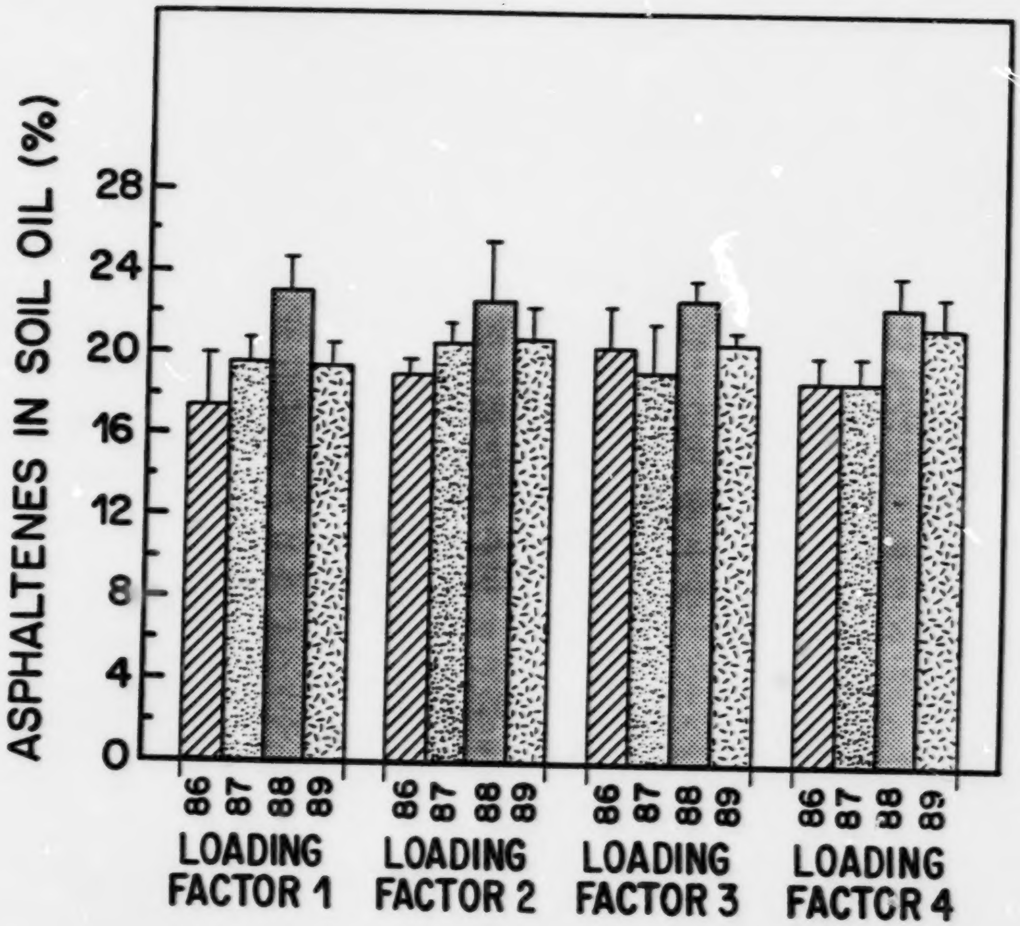

Figure 3. Percentage of oil composed of asphaltenes that was extracted from Lloydminster soils treated with oily wastes 1982 to 1985 inclusively and measured in 1986 and 1989. Loading factors indicate relative rates of oil application (1 = low, 4 = high). Error bars are S.D., n = 4.

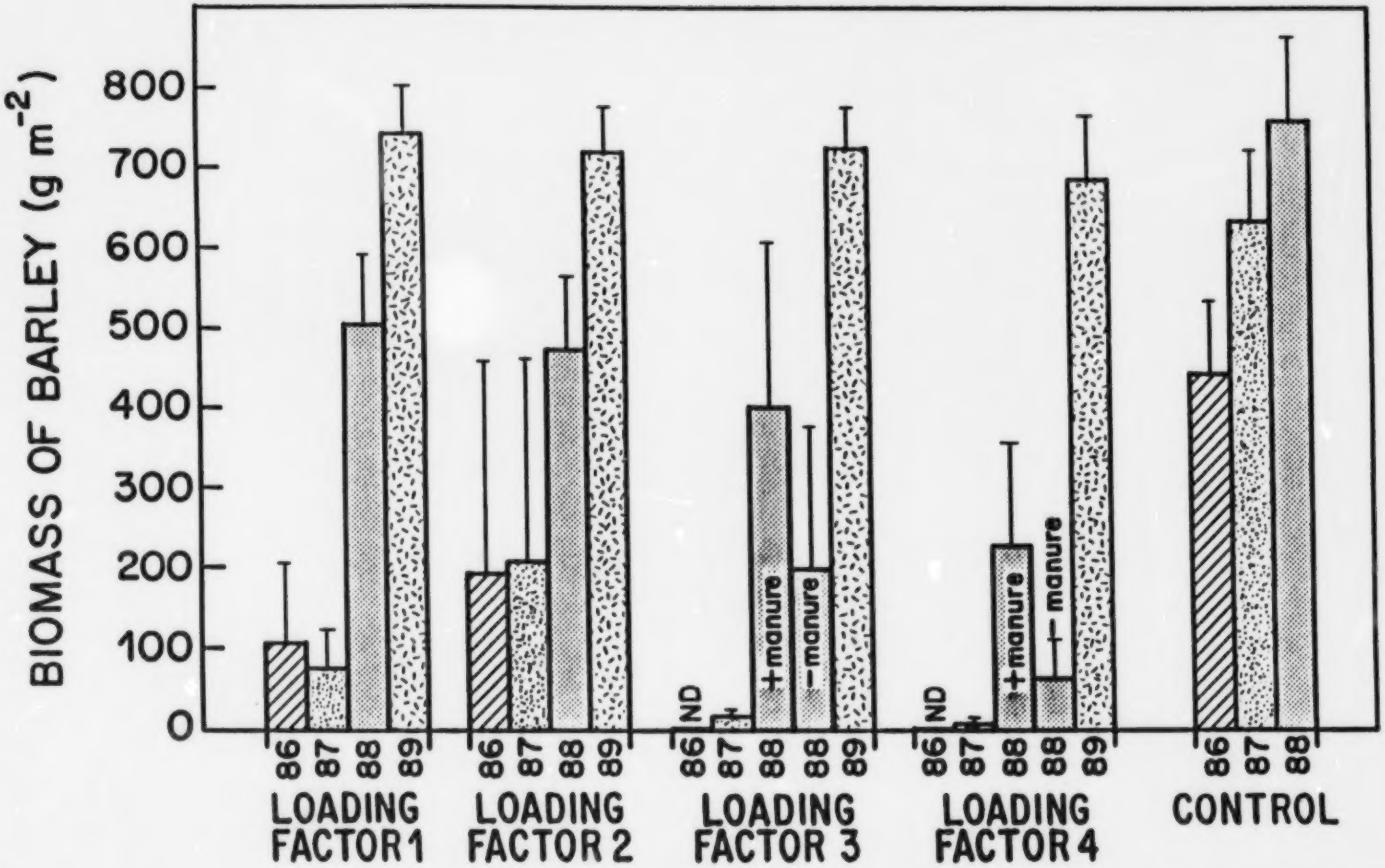

Figure 4. Yield of barley planted on the Lloydminster land treatment plots and on oil-free soil one to four years after the last application of oily wastes. Loading factors are the relative amounts of oil applied (1 = low, 4 = high). Manure applied to half the plots in 1988. Error bars are S.D., n = 4. ND = not determined due to very low biomass.

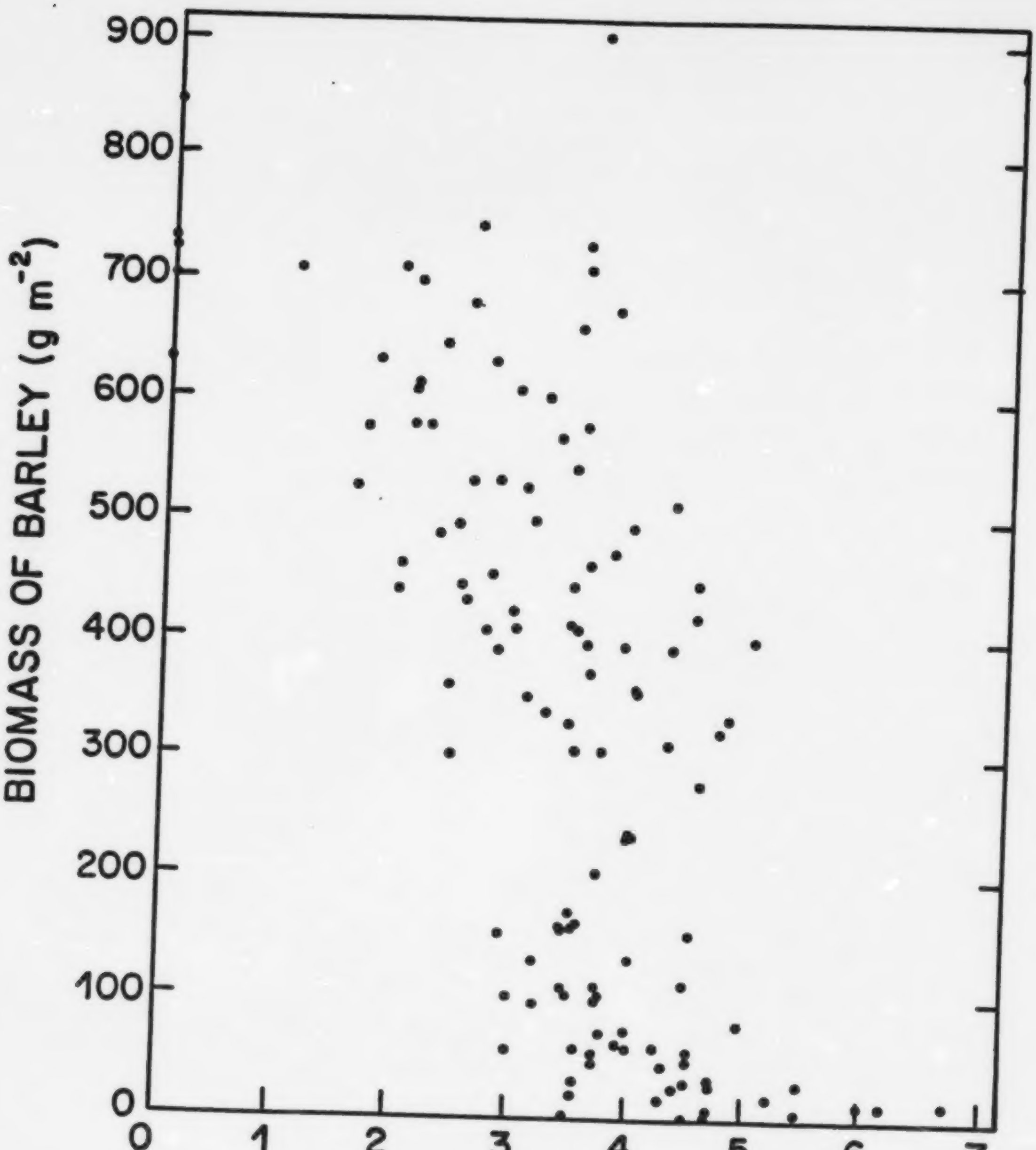

Figure 5. Relationship between soil oil content and barley biomass of clip plots on Lloydminster land treatment plots 3 years after the last application of oily wastes (1988).

17.0

OVERVIEW OF THE US EPA'S SUBSURFACE CLEANUP AND MOBILIZATION PROCESSES (SCAMP) RESEARCH INITIATIVE

by

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ABSTRACT

The Subsurface Cleanup and Mobilization Processes (SCAMP) research initiative is an EPA funded and directed five-year effort to improve the efficiency of pump-and-treat remedial actions at contaminated sites. The SCAMP research effort was initiated in 1990 in recognition of the fact that, although pump and treat was one of the most widely used ground-water remediation technologies, many pump and treat systems were performing poorly in relation to their original design goals. The goal of SCAMP research is more effective pump-and-treat remediations, particularly for sites contaminated by dense non-aqueous phase liquids (DNAPLs). Research leading to this goal is organized into three categories of applied research: (1) the development and evaluation of improved techniques for site characterization, (2) research on controlling and optimizing subsurface fluid movement, and (3) development and evaluation of techniques to accelerate pump-and-treat remediation. The program also includes some research on subsurface contaminant transport and fate processes. The paper discusses projects currently under way and the results expected from this research.

OVERVIEW OF THE US EPA'S SUBSURFACE CLEANUP AND MOBILIZATION PROCESSES (SCAMP) RESEARCH INITIATIVE

1. INTRODUCTION

The Subsurface Cleanup and Mobilization Processes (SCAMP) research initiative is an EPA funded and directed effort to improve the efficiency of pump-and-treat remedial actions at contaminated sites. The SCAMP research effort was initiated in 1990 in recognition of the fact that, although pump and treat was one of the most widely used remediation technologies, many pump-and-treat systems were performing poorly in relation to their original design goals. SCAMP was envisioned as a five-year effort to begin in 1990. This report provides an overview of research currently being conducted under this program as well as work planned for the near future.

This report begins with a summary of the problems that led to the initiation of SCAMP and the goals of the research program. This is followed by an overview of the SCAMP research, and the relationship of the SCAMP research to the problems encountered in pump and treat. The report concludes with a discussion of specific research projects currently underway and plans for work in the near future.

2. BACKGROUND

Pump and treat is one of the most widely used remediation technologies for dealing with contaminated ground water in the United States. Pump-and-treat systems are designed with two objectives in mind:

1) to use the hydraulic gradients created by the pumping system to prevent the further spread of the contaminant plume, and
2) to reduce the concentration of pollutants in the aquifer below a predetermined limit.

The extent to which these two objective are achieved varies from site to site, but, as a rule, the second objective is achieved much less often than the first.

For the purposes of this report, the term "pump and treat" will be used in the most general sense to mean a system that attempts to remediate an aquifer by extracting the contaminants from the subsurface and then treating them. This includes the removal of dissolved contaminants by pumping of ground water, as well as by the addition of chemical or physical agents to the pumping system.

In the late 1980's, it became apparent that many pump-and-treat systems were performing poorly in relation to their design goals. More specifically, these systems would

1) fail to reach their treatment goals, or
2) take much longer to reach that goal than had been anticipated, and
3) cost much more than had been anticipated at the start of the remediation.

The USEPA's awareness of the situation was originally based on reports from the field, from requests for assistance from Superfund remedial project managers (RPMs), and from research conducted at the EPA's Robert S. Kerr Environmental Research Laboratory (RSKERL) in Ada, Oklahoma.

The early reports from the field, which were largely anecdotal in nature, were confirmed by a more formal study, often referred to as the "Nineteen Site Study", conducted by the Hazardous Site Control Division of the EPA's Superfund program office. Typical system behavior reported in this study included a large initial removal of contaminant mass with a concomitant drop in the concentrations of the contaminants in the pumped water and in monitoring wells. However, after this initial success, the concentration of the contaminant leveled off at a value well above the treatment goal, or only very slowly approached that goal, which was often the maximum contaminant level allowed in public drinking water supplies. To reach the design goal would take tens to hundreds of years and cost much more than originally expected.

The study identified characteristics of contaminated aquifers that seemed to be important in limiting the success of pump and treat. Three of these characteristics were:

1) aquifer heterogeneity, particularly fractured rock and strongly layered sediments,
2) sorption of the contaminant to the aquifer solids, and
3) the presence of a separate immiscible non-aqueous phase liquid (NAPL).

These same characteristics limit the success of other aquifer remediation technologies. In addition, the design of many of the pump-and-treat systems was hampered by a poor understanding of the nature and extent of the contamination problem as a result of inadequate site characterization. For example, the presence of dense non-aqueous phase liquids (DNAPLs) was rarely recognized or considered in the design of the system. Inadequate site characterization also made it difficult to evaluate the performance of the treatment systems.

Another factor that has limited the success of pump-and-treat systems is that there is a very small set of successful systems. There is essentially no base of field-tested knowledge to know what works and what doesn't, or to set realistic goals that will be protective of public health and the environment. There is even less experience in the use of techniques that could enhance or accelerate pump and treat.

On the other hand, there appear to be many promising opportunities to improve the situation with regard to pump and treat. This belief that pump and treat could be made more effective was the primary motivation behind the initiation of the SCAMP research initiative.

3.0 SCAMP RESEARCH

3.1 Overview

Figure 1 shows the overall structure of the SCAMP research program. The research is directed at the goal of more effective pump-and-treat remediations. Research leading to this goal is directed at removing the barriers to pump and treat that were identified earlier and is organized into three categories of applied research:

(1) the development and evaluation of improved techniques for site characterization, (2) research on controlling and optimizing subsurface fluid movement and mathematical modeling, and (3) development and evaluation of techniques to accelerate pump-and-treat remediations. This applied research is supplemented by the additional research necessary to fill in the gaps in our understanding of the basic processes controlling contaminant transport and fate. The research is also coordinated with the RSKERL's Technology Support Center to ensure that results of the research are efficiently transferred to the appropriate audience.

The main audience for the applied research is the remedial project manager (RPM) who is the EPA person overseeing the site cleanup project. SCAMP is to provide the RPM, or others in equivalent positions, improved decision-making tools to (1) determine when pump and treat is the best option for remediation, (2) decide what steps should be taken to improve the outcome of a pump-and-treat remedial action, and (3) make reasonably reliable estimates of the outcome of a pump-and-treat action. In short, SCAMP plans to make a start on providing the kind of basic engineering design information for pump and treat that has been developed in other areas.

Other audiences for the SCAMP research include the Superfund program managers in the EPA Regional and Headquarters offices and their equivalents in other remedial programs such as the EPA's RCRA corrective action program. We also expect that results of the research will be made available to the broader science and engineering community involved in the remediation of waste sites, and that it will be published in the appropriate scientific and engineering journals.

3.2 Specific Emphasis of SCAMP

Research under SCAMP was initiated in 1991, and a decision was made to focus the research on pump-and-treat remediation of DNAPL contamination, particularly that resulting from improper disposal of chlorinated solvents. (In the context of this report, DNAPL refers to only to a separate dense non-aqueous phase

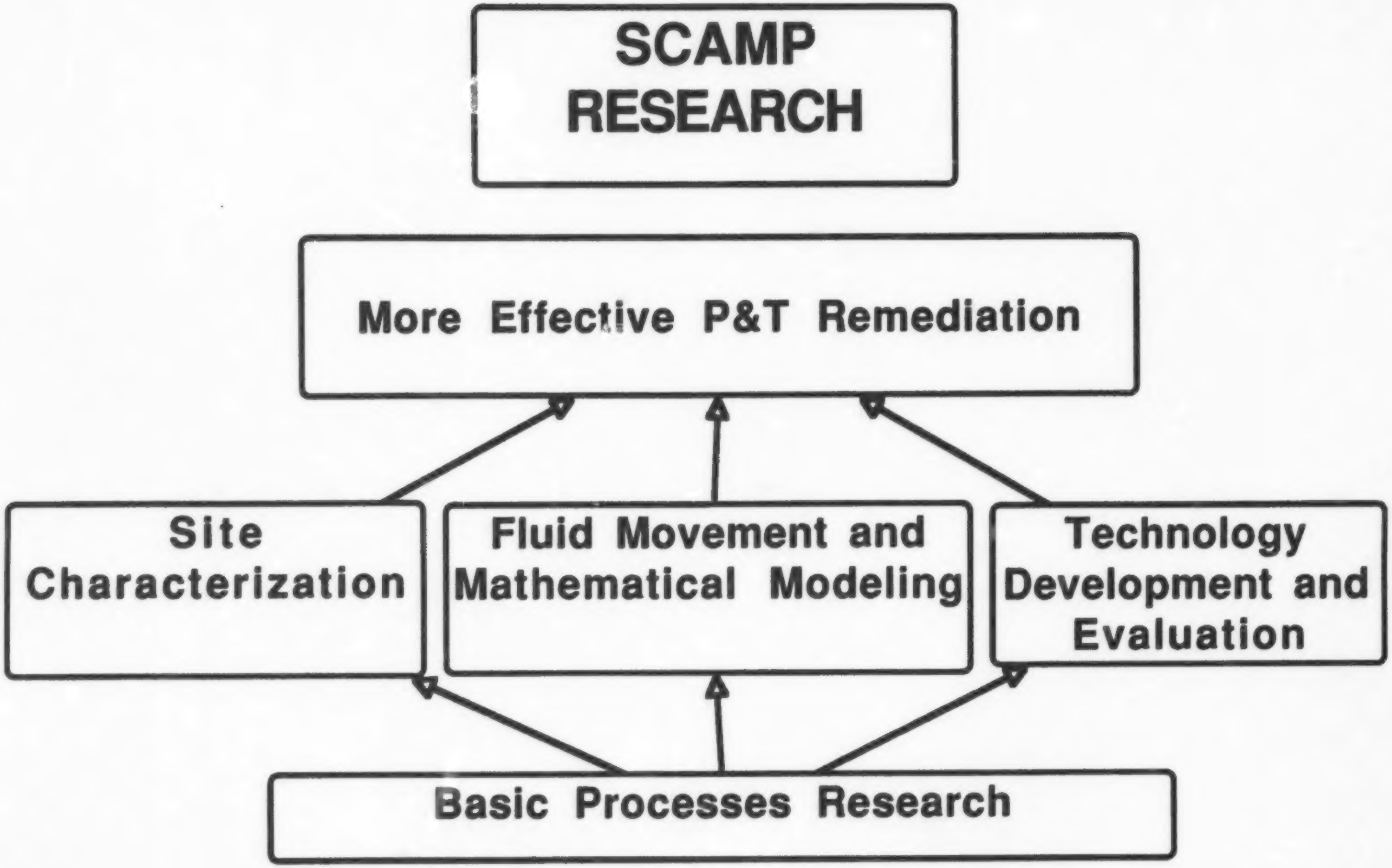
SCAMP
RESEARCH
More Effective P&T Remediation
Site Characterization
Fluid Movement and Mathematical Modeling
Technology Development and Evaluation
Basic Processes Research

Figure 1. Overview of SCAMP Research

liquid, such as trichloroethene (TCE) and not to the dissolved or sorbed phase of the compound.) The decision to focus on DNAPLs was based on the significance of the problem of DNAPL contamination and the funding available to SCAMP. Of all the problems encountered in restoring contaminated ground water, contamination from DNAPLs seems to be among the most difficult to deal with, and was identified in the "Nineteen Site Study" as one of the major causes of the poor performance of pump and treat. Practical experience and mathematical modeling have both indicated that where DNAPL is present, the time to reduce the concentration of the contaminant to below the maximum allowed in drinking water could be hundreds to thousands of years using conventional pump and treat.

The movement of DNAPLs in the subsurface is complex and site specific. It is also, to a variable extent, decoupled from the movement of ground water. Because of their high specific gravity, on the order of 1.5 for chlorinated solvents, the movement of DNAPLs is strongly driven by the force of gravity and is very dependent on the structure of the subsurface environment in which it is found, particularly small-scale heterogeneities. Direct determination of whether or not DNAPLs are present at a site, and if so, to what extent, is often beyond the current state of the art. Without basic information on the nature and extent of the contamination at a site, it is difficult to design and implement an effective remediation. Thus, site characterization seems to be one logical area to emphasize in the SCAMP research effort.

The research on controlling and optimizing subsurface fluid movement was undertaken for several reasons. One was that various schemes for improving the efficiency of pump and treat, such as pulsed pumping, have been proposed, but not critically evaluated. There is also a decided lack of readily available guidance on the most effective ways to recover DNAPL when it is found in the free product state in the subsurface. Many proposals for enhancing the effectiveness of pump and treat rely on the addition of chemical additives to enhance the solubility of the DNAPL in water, but there is a poor base of knowledge on the most effective ways to accomplish this under the conditions in which ground water is commonly found.

In addition, there is a need for further development and testing of models that describe the movement of multiphase fluid systems.

The last area of applied research is the development and evaluation of methods to enhance the effectiveness of pump and treat. Several techniques to improve the efficiency of pump-and-treat remediation and the rate of contaminant removal have been proposed and some are being put in to practice. For example, the use of surfactants and solvents to increase the solubility and/or mobility of DNAPLs has been proposed and put into practice on a limited scale. However, there are major unanswered questions about the efficacy, feasibility, and safety of increasing the removal rate by injecting these materials into the subsurface. In addition, many of the same problems that plague conventional pump and treat, such as spatial variability and a lack of information on the distribution of the contaminants, will hamper the use of accelerated remediation technologies as well.

4.0 SCAMP RESEARCH PROJECTS

Figure 2 shows a more-detailed overview of the work being conducted and planned under SCAMP. In addition to the projects shown in Figure 2, there are a number of other research projects being conducted at RSKERL and other EPA laboratories that address the issues shown here, and these are being coordinated with SCAMP research. SCAMP research was planned as a combination of short-term efforts, largely synthesizing existing information, and longer term efforts to discover new information.

4.1 Site Characterization Projects

The first project in this area will produce a guidance document that can be used to plan and implement the investigation and characterization of a site that is suspected of having ground water contaminated by DNAPLs. The document will focus on characterization activities that, as a rule, will be specific to sites suspected of contamination by DNAPLs. The goal of this project is to provide a document

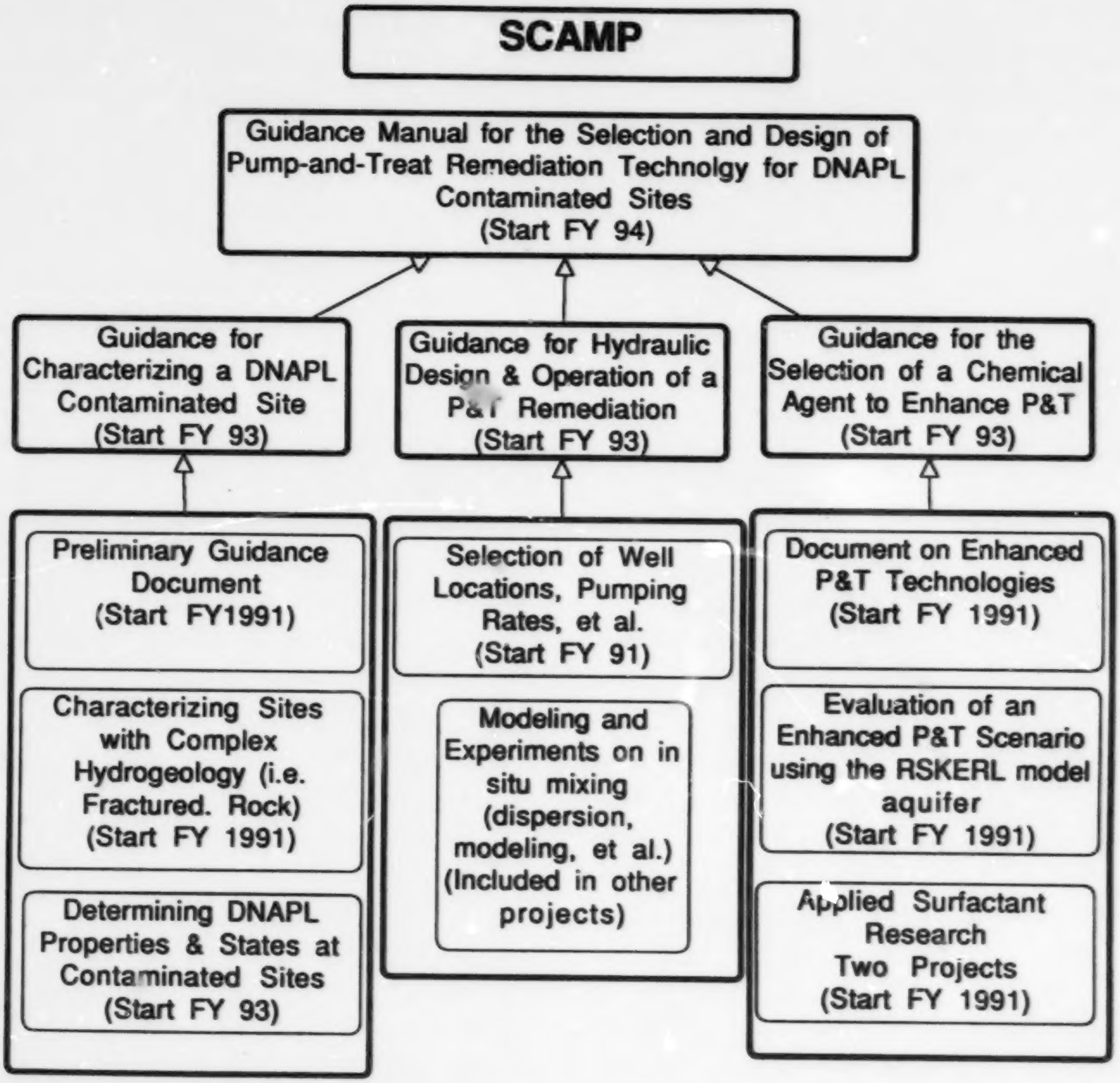
SCAMP
Guidance Manual for the Selection and Design of Pump-and-Treat Remediation Technolgy for DNAPL Contaminated Sites (Start FY 94)
Guidance for Characterizing a DNAPL Contaminated Site (Start FY 93)
Guidance for Hydraulic Design & Operation of a P&T Remediation (Start FY 93)
Guidance for the Selection of a Chemical Agent to Enhance P&T (Start FY 93)
Preliminary Guidance Document (Start FY1991)
Characterizing Sites with Complex Hydrogeology (i.e. Fractured. Rock) (Start FY 1991)
Determining DNAPL Properties & States at Contaminated Sites (Start FY 93)
Selection of Well Locations, Pumping Rates, et al. (Start FY 91)
Modeling and Experiments on in situ mixing (dispersion, modeling, et al.) (Included in other projects)
Document on Enhanced P&T Technologies (Start FY 1991)
Evaluation of an Enhanced P&T Scenario using the RSKERL model aquifer (Start FY 1991)
Applied Surfactant Research Two Projects (Start FY 1991)

Figure 2. SCAMP Research Projects

that will synthesize the best information available to describe and evaluate those activities that can be used to determine (a) the likelihood that a site is contaminated by DNAPLs, (b) the spatial and temporal distribution of the DNAPL contamination, and (c) the best course of action to remediate the site. This project is expected to be completed by September 1992. It is also expected that this document will be revised at least once during the five-year life span of SCAMP.

The second project is a field study to investigate methods to characterize fractured rock sites for pump and treat. The project is being conducted by the Lawrence Berkeley Laboratory (LBL) at a quarry in California. The project is combining geological, geophysical, and hydrologic testing, with the modeling of flow and transport in the fractured rock system. The project is focusing on the movement of water and dissolved contaminants for several reasons. One reason is that the current state of knowledge of dissolved contaminant transport in fractured rock is far short of what is needed and that understanding dissolved contaminant transport should logically serve as a predecessor for understanding multiphase fluid flow in fractured rock. A second reason is that it is impossible to use DNAPLs as tracers in field projects in the US.

Future work in the area of site characterization will focus on methods to measure the distribution and composition of DNAPLs at contaminated sites. This work was scheduled to begin in 1992, but because of changes in funding will most likely be postponed to 1993.

4.2 Fluid Movement and Mathematical Modeling

The first project in this area is an effort to use computer simulations to evaluate scenarios designed to make pump and treat more effective. The project will examine various configurations of wells and well screens, pumping schemes, and the effect of subsurface heterogeneity and the physical and chemical properties of the contaminants. The results of this project are expected to provide a clearer understanding of the limits of pump-and-treat remediation and the methods needed to achieve those limits. This project is expected to be completed in the spring of 1993 and will be used to plan possible field projects.

Other work on fluid movement and mathematical modeling is being carried out under other research programs or as part of other SCAMP projects.

4.3 Technology Development and Evaluation

This is the area of greatest emphasis for SCAMP research. The first project in this area is the preparation of a comprehensive state-of-the-art summary and evaluation of *in-situ* treatment technologies as they pertain to the mobilization and removal of subsurface DNAPL. This is a relatively short-term effort and a report will be available in the spring of 1993. The completed document will serve as a resource for determining the options that are available for DNAPL contamination and for targeting further research.

SCAMP is sponsoring three projects dealing with the use of surfactants for contaminant removal. Chemical additives, such as surfactants or miscible solvents, appear to have real potential to increase the efficiency of pump and treat for DNAPL-contaminated ground water. Surfactants should be able to improve pump and treat by two mechanisms: (1) by increasing the solubility of DNAPLs through the formation of micellar solutions and (2) by increasing DNAPL mobility by the formation of microemulsions. However, there is also a long list of questions that need to be answered before surfactants will be ready to use as an off-the-shelf remedy for subsurface contamination. Miscible solvent solutions, such as ethanol/water have the potential to significantly increase DNAPL solubility and are another promising technology.

The first two surfactant projects are laboratory studies with the aim of developing safe, effective, and predictable surfactant systems that can be used for subsurface contaminant removal. The two projects are examining different surfactant systems with one group focusing on existing surfactants with FDA approved food additive status, while the other project is emphasizing the development of biodegradable, non-toxic surfactant systems. Both research groups have extensive experience with the use of surfactants for enhanced oil recovery and are hoping to transfer this experience to the removal of DNAPL. Work on these projects will be completed in 1994, and will also feed into a pilot-scale remediation project to be described next.

The third project is an evaluation of an enhanced pump-and-treat remediation using one of RSKERL's large physical model aquifers shown in Figure 3. The physical models, with dimensions of 1.22 m x 4.88 m x 1.5 m, are composed of three layers. At the bottom is a 0.3 m clay layer, which serves as an aquitard. Above this is a 0.3 m sand layer through which ground water flows in a uniform pattern at a rate of approximately 0.15 m/day. At the top is a loamy sand layer with a thickness of approximately 0.61 m which contains the capillary fringe and the vadose zone. The system is open to the atmosphere at the top, while the inside is lined with stainless steel and glass. The system is instrumented with 60 multi-level samplers, each of which has six sampling points.

This project will use the results of the two laboratory surfactant studies to design and implement an enhanced pump-and-treat remediation of a tetrachloroethene (PCE) spill. The project will also use electromagnetic techniques to attempt to monitor the DNAPL movement and the progress of the remediation. Work is currently underway on this project to characterize the aquifer flow system and to install and test necessary monitoring equipment. This project is expected to be completed in 1994.

Planning is currently underway for a pilot-scale field project to use an ethanol/water mixture to remedy a small spill involving a mixture of aviation gasoline and PCE. The PCE is probably not present as DNAPL but is dissolved in the aviation gasoline which is present as a separate phase. The project will use two cells constructed of sheet piling to compare the efficiency of removing the material by pumping water only through one of the cells and pumping an ethanol/water

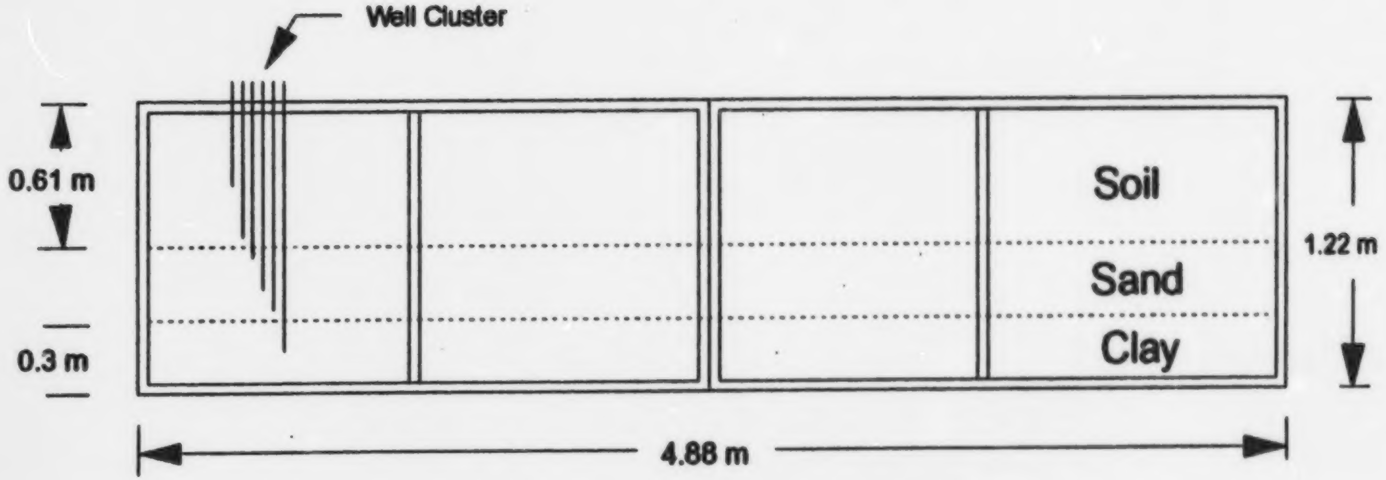
Well Cluster
0.61 m
0.3 m
Soil
Sand
Clay
1.22 m
4.88 m

Figure 3. Schematic of RSKERL Model Aquifer

mixture through the other. If the ethanol/water mixture demonstrates a significant advantage over water alone it will be used to remediate the entire site.

5.0 FUTURE PLANS

Additional work under SCAMP is dependent on the level of funding provided. At the present time the funding picture is sufficiently unclear that it would be unwise to lay out a specific plan of action for the next year, let alone farther into the future. Several of the projects mentioned above will continue. If money is available to undertake new projects, the emphasis will probably be on the area of site characterization and pilot-scale field studies for the surfactant technologies

DISCLAIMER

Al;though the work decribed in this article has been funded by the United States Environmental Protection Agency, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

BIOGRAPHICAL SKETCH

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IRON AND MANGANESE PRETREATMENT FOR PUMP-AND-TREAT CLEANUP SYSTEMS

BY

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ABSTRACT

The aim of this investigation was to develop a simple and effective iron and manganese removal process train, based on three diffused aeration technologies. The catalytical effect of iron(III) and manganese(IV) oxides on the oxidation of iron(II) and manganese(II) in a diffused aeration vessel was assessed by recirculating either a fraction of the diffused aeration vessel effluent or sludge, collected from the sand filter backwash water, to the diffused aeration vessel influent.

The recirculation of 20% of the diffused aeration vessel effluent, consisting mainly of iron(III) oxides, did not promote iron or manganese oxidation.

The recirculation of sludge, consisting of iron(III) and manganese(IV) oxides, was found to adversely impact the performance of the process train.

The study resulted in the optimization of a simple process train, consisting of diffused aeration - on-line chemical oxidant addition ($Cl0_2$) - direct contact sand filtration.

IRON AND MANGANESE PRETREATMENT FOR PUMP-AND-TREAT CLEANUP SYSTEMS

1.0 INTRODUCTION

Roughly forty percent of the public water supplies in Canada have iron and manganese above their respective recommended maximum concentrations of 0.30 mg/L and 0.05 mg/L[1].

The problems associated with the presence of these two metals extend beyond factors of aesthetics and potability. In addition to physical fouling problems, iron and manganese may stimulate growth of microorganisms, e.g. *Pseudomonas*, Iron Bacteria, in groundwater treatment plants, in distribution systems and in reservoirs.

The contamination of groundwater by undesirable organic compounds has resulted in the development of process trains aimed at the removal of the organics of concern. However, when iron and/or manganese are present in the groundwater, treatment efforts have to focus initially on the removal of these inorganics prone to precipitation. This will minimize fouling (physical and biological) of the downstream unit processes responsible for the removal of the organics of concern from the groundwater.

During 1988-89, a site remediation project was conducted in Ville Mercier (Québec), under the auspices of the Wastewater Technology Centre (WTC). One of the objectives of this research, technical development and field demonstration project was to develop an effective iron removal process train, as a pretreatment step prior to the removal of the organic contaminants from the groundwater[2].

For the Ville Mercier Project, seven iron removal process trains were evaluated at pilot scale. These are presented in Table 1. Attempts were made to minimize the number of unit operations required, other capital and operating costs, and sludge production. The process train, comprising fine pore diffused aeration followed by direct contact sand filtration, was demonstrated effective in oxidizing, precipitating and removing iron from the groundwater, to levels consistently below the recommended maximum concentration of 0.30 mg/L.

TABLE 1 IRON REMOVAL PROCESS TRAINS TESTED AT VILLE MERCIER, QUÉBEC (1988-89)[2]

1.	Chemical Oxidation - Coagulation - Flocculation - Sedimentation - Sand Filtration
2.	Chemical Oxidation - Direct Contact Sand Filtration
3.	Diffused Aeration - Coagulation - Flocculation - Sedimentation - Sand Filtration
4.	Diffused Aeration - Chemical Oxidation - Direct Contact Sand Filtration
5.	Diffused Aeration - On-Line Coagulant Addition - Direct Contact Sand Filtration
6.	Diffused Aeration - On-Line Flocculant Addition - Direct Sand Filtration
7.	Diffused Aeration - Direct Contact Sand Filtration

During the study, the catalytic effect of iron(III) to promote iron(II) oxidation in the sand filter was consistently recorded. This complete oxidation in the sand bed suggested an adsorption and an ensuing contact/catalytic oxidation of iron(II) onto previously deposited iron(III) flocs.

The purpose of the present investigation is to improve the performance of the diffused aeration - direct contact sand filtration process train, by using the catalytical effect of recycled solids, e.g. iron(III), manganese(IV), to promote iron(II) and manganese(II) oxidation in a diffused aeration vessel. The study was conducted in the Regional Municipality of Waterloo, by the Wastewater Technology Centre. The experimental field study was initiated in April 1991, and was concluded in August 1991.

The study was funded by the national Groundwater and Soil Remediation Program (GASReP), the Wastewater Technology Centre (WTC) and the Regional Municipality of Waterloo.

2.0 STUDY OBJECTIVES

The overall objective of the study was to increase the rates of oxidation of iron(II) and manganese(II) in a diffused aeration vessel. Solids recycle to the aeration vessel, was used to achieve the objective. Two options were considered: 1) the recycle of a fraction of the aeration vessel effluent to its influent line (Enhanced Aeration Process I: Continuous Recycle Loop), and 2) the addition of sludge collected from the sand filter backwash water to the diffused aeration vessel influent line (Enhanced Aeration Process II: Sludge Recycle).

The aim of the study was to develop a simple diffused aeration - direct contact sand filtration process train, effective in removing iron and manganese from the groundwater, to levels below their respective maximum recommended concentrations of 0.30 mg/L and 0.05 mg/L.

Specific objectives were to develop and conduct performance evaluations of the following process trains:

1. Conventional Diffused Aeration Process:
   Diffused Aeration - Chemical Oxidant Addition (if required) - Direct Contact Sand Filtration
2. Enhanced Aeration Process I:
   Diffused Aeration - Continuous Recycle Loop - Chemical Oxidant Addition (if required) - Direct Contact Sand Filtration
3. Enhanced Aeration Process II:
   Diffused Aeration - Sludge Recycle - Chemical Oxidant Addition (if required)- Direct Contact Sand Filtration

3.0 PILOT PLANT SET-UP

A schematic of the pilot plant is shown in Figure 1.

4.0 EXPERIMENTAL ACTIVITIES AND CONDITIONS

Activities and conditions for the study are summarized in Table 2. Based on the findings from the Ville Mercier (Québec) study[2], the ranges of the parameters outlined in Table 2 were selected. The experimental program for each activity is explained in the following sections of the paper.

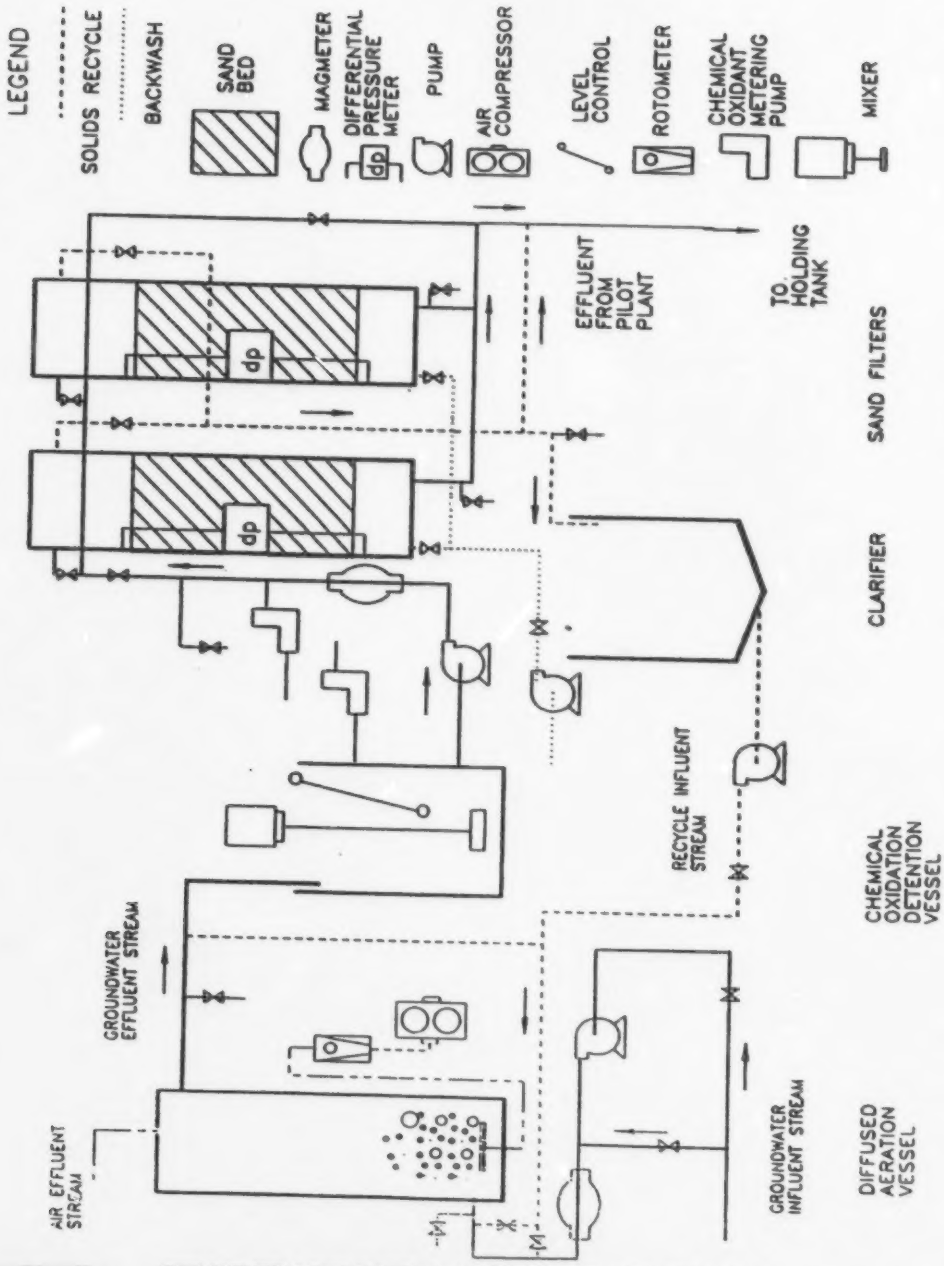
LEGEND
SOLIDS RECYCLE
BACKWASH
SAND BED
MAGMETER
DIFFERENTIAL PRESSURE METER
dp
PUMP
AIR COMPRESSOR
LEVEL CONTROL
ROTOMETER
CHEMICAL OXIDANT METERING PUMP
MIXER
TO HOLDING TANK
EFFLUENT FROM PILOT PLANT
SAND FILTERS
CLARIFIER
RECYCLE INFLUENT STREAM
CHEMICAL OXIDATION DETENTION VESSEL
GROUNDWATER EFFLUENT STREAM
AIR EFFLUENT STREAM
GROUNDWATER INFLUENT STREAM
DIFFUSED AERATION VESSEL

FIGURE 1 PILOT PLANT SCHEMATIC FLOW DIAGRAM

TABLE 2 EXPERIMENTAL ACTIVITIES AND CONDITIONS

ACTIVITY	PARAMETER	RANGE
1. Diffused Conventional Aeration Process	Q_{GW} (HRT)* Q_A/Q_{GW} (pH)**	5 to 60 L/minutes 2.5 to 15.0
2. Enhanced Aeration Process I: Continuous Recycle Loop	Recycle Ratio	10% to 20%
3. Enhanced Aeration Process II: Sludge Addition	Sludge Addition Factor (total iron increase in aeration vessel)	100% to 500%
4. Chemical Oxidant Addition (to supplement Mn oxidation, if required)	Type Dosage Reaction Time	H_2O_2, ClO_2, Cl_2, $KMnO_4$ 0.25 to 2.00 x stoichiometric 15 sec to 30 min
5. Performance Evaluation of the Optimum Process Train in a Continuous Mode of Operation	Time Q_{GW} Q_A/Q_{GW} Solids Recycle	≥ seven days optimum optimum optimum

* The hydraulic retention time (HRT) of the groundwater in the aeration vessel is a function of the groundwater flow rate.

** The aeration pH is principally a function of the air to groundwater flow rates.

5.0 PILOT SCALE TREATABILITY STUDIES: CONVENTIONAL DIFFUSED AERATION PROCESS

5.1 Diffused Aeration Process

Factorial design studies were conducted to maximize the oxidation of iron(II) and of manganese(II) in the diffused aeration vessel.

Twenty-three runs were completed to evaluate the optimum experimental conditions in the diffused aeration vessel for iron and manganese oxidation and to determine the associated oxidation profile.

The pH of the raw groundwater, prior to aeration, averaged 7.1. The concentration of total iron in the raw groundwater varied between 1.91 mg/L and

2.31 mg/L. The concentration of total manganese in the raw groundwater varied between 0.08 mg/L and 0.14 mg/L.

Iron(II) was effectively oxidized at a pH of 7.6 as shown in Figure 2. Throughout the performance evaluation of the diffused aeration process, iron oxidation, i.e. ferric formation, was at a minimum for pH values of 7.4 and 7.8, and at a maximum for pH values of 7.6 and 7.7. At a pH of 7.6, a hydraulic retention time of approximately 28 minutes was necessary to completely oxidize iron(II) to iron(III).

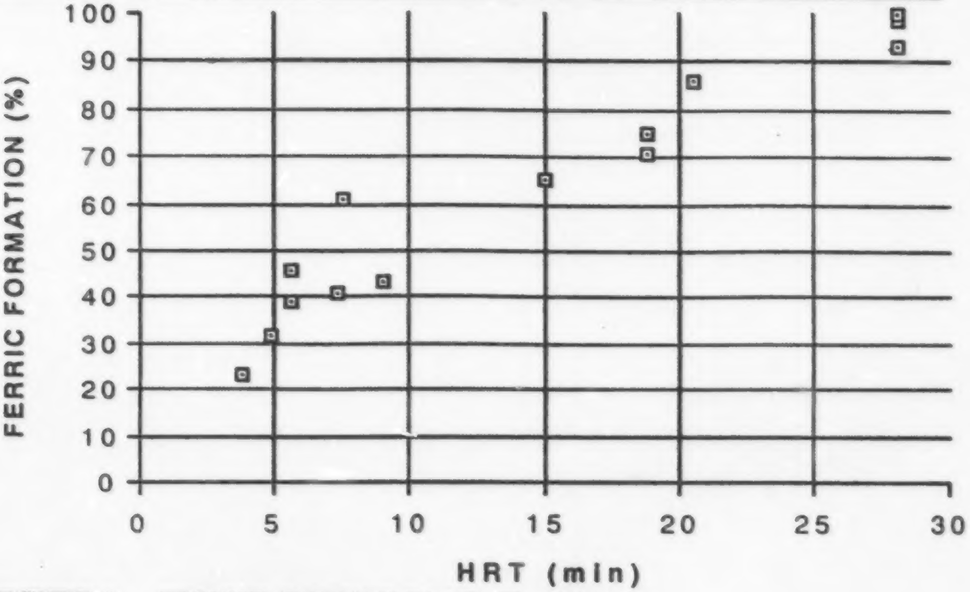

FIGURE 2 **IRON(II) OXIDATION AT pH = 7.6**

Manganese(II) was not oxidized in the diffused aeration vessel under any of the experimental conditions.

Two main conclusions were derived from the performance evaluation of the diffused aeration process. These were:

1. Diffused aeration of the groundwater is technically feasible and was found

effective in oxidizing iron(II) to iron(III) at a pH of 7.6 and a hydraulic retention time of 28 minutes.

2. Diffused aeration was not found effective for the oxidation of manganese(II) to manganese(IV) for pH equal to or below 7.8. Hence, the addition of a chemical oxidant will be required, following diffused aeration, to oxidize manganese(II).

5.2 Diffused Aeration - Chemical Oxidation Process

Twenty-two batch pilot scale runs were completed on aerated groundwater to evaluate the optimum chemical oxidant dose and reaction time necessary to oxidize manganese(II). The concentration of total manganese in the raw groundwater varied between 0.12 mg/L and 0.26 mg/L.

The following chemical oxidants were evaluated: hydrogen peroxide (H_2O_2), sodium hypochlorite (NaOCl), chlorine dioxide (ClO_2) and potassium permanganate ($KMnO_4$).

The performance of hydrogen peroxide for manganese(II) oxidation and precipitation was poor. No evidence of oxidation and precipitation, within experimental error, was observed during stoichiometric studies ranging from 1.3 to 60 x stoic, reaction times from 1 minute to 20 minutes, and at a pH of 7.6. Therefore, further experimentation with hydrogen peroxide was not pursued.

The performance of potassium permanganate for manganese(II) oxidation was good. At 1.3 x stoichiometric dosage, almost complete oxidation of manganese(II) occurred at two minutes (91%) and at 12 minutes (96%), resulting in a soluble manganese(II) concentration of 0.01 mg/L. At 3.2 x stoichiometric dosage, a substantially high concentration of manganese remained in solution. This result was attributed to the presence of excess unreacted potassium permanganate.

The performance of sodium hypochlorite for manganese(II) oxidation was poor. Adequate oxidation, resulting in a soluble manganese(II) concentration equal to or below 0.05 mg/L, was observed only when the sodium hypochlorite dosage was 50 x stoic. For example, under these conditions, 67% of the manganese(II) was oxidized after two minutes, resulting in a soluble manganese(II) concentration of

0.03 mg/L.

The performance of chlorine dioxide for manganese(II) oxidation was good. At 6.5 x stoichiometric dosage ($ClO_2 \rightarrow Cl^-$), virtually complete manganese(II) oxidation took place. Manganese(II) concentrations of ≤ 0.01 mg/L remained in the treated water. Reaction rates were rapid and comparable to those observed when using potassium permanganate.

In conclusion, although potassium permanganate was very effective for manganese(II) oxidation, further experimentation with it was not pursued. This was due to the potential operational problems, such as the presence of unreacted permanganate in the treated waste, when an oxidizing contact filter is not utilized as a capture medium. Hence, among the chemical oxidants studied, chlorine dioxide was the oxidant of choice.

5.3 Diffused Aeration - Chemical Oxidation - Direct Contact Sand Filtration (A - O - F) Process Train: Performance Evaluation

The optimum process train was operated continuously for five days, under the following operating requirements:

Diffused Aeration Vessel:	pH = 7.6
	Hydraulic retention time = 28 minutes
On-line Chemical Oxidant Addition:	Oxidant type = ClO_2
	Oxidant dosage = 7 x stoic
	Reaction time = 2 minutes
Direct Contact Sand Filtration:	Sand bed depth = 1.1 m
	Sand effective diameter = 0.52 mm
	Filtration rate = 4.25×10^{-3} m/s

During continuous operation, the process train removed an average of 98% iron and 93% manganese. Groundwater entered the train with 2.07 mg/L iron and 0.15 mg/L manganese, and left with 0.05 mg/L iron and 0.01 mg/L manganese. Breakthrough of iron (> 0.30 mg/L) and of manganese (> 0.05 mg/L) did not occur during the period, so data for calculating the bed's maximum storage capacity were not obtained. The mass storage capacity of the sand filter was greater than 1.0 kg suspended solids/m^3 sand, of which 0.4 kg was Fe and 0.03 kg was Mn.

Figures 3 and 4 illustrate the performance profile of the process train for iron and manganese removal.

6.0 PILOT SCALE TREATABILITY STUDIES: ENHANCED AERATION PROCESS I - CONTINUOUS RECYCLE LOOP

6.1 Diffused Aeration - Continuous Recycle Loop Process

Seventeen runs were completed to evaluate the rates of oxidation of iron and manganese in the diffused aeration vessel, when 10% or 20% of the effluent from the vessel was recycled to its influent point.

The concentration of total iron in the raw groundwater varied between 1.89 mg/L and 2.09 mg/L. The concentration of total manganese in the raw groundwater varied between 0.11 mg/L and 0.20 mg/L. Iron(II) was effectively oxidized at a pH of 7.6 (Figure 5). The oxidation of 95% of the iron still required a hydraulic retention time of 28 minutes, even when 20% of the effluent was recycled.

Manganese(II) was not oxidized within experimental error, in the diffused aeration vessel under any of the experimental conditions.

Two main conclusions were drawn from the performance evaluation of the diffused aeration - continuous recycle loop process. These were:

1. At these ratios, the design/operating requirements for iron(II) oxidation were similar to those of the conventional diffused aeration process.
2. The oxidation of manganese(II) was not promoted. Hence, the addition of a chemical oxidant will be required, following aeration, to oxidize manganese(II).

6.2 Diffused Aeration - Continuous Recycle Loop - Chemical Oxidation - Direct Contact Sand Filtration (A(Recycle) - 0 - F) Process

The diffused aeration vessel was operated at a pH of 7.6, a hydraulic retention time of 28 minutes and a recycle ratio of 20%. ClO_2, at 6 x stoic, was added to the

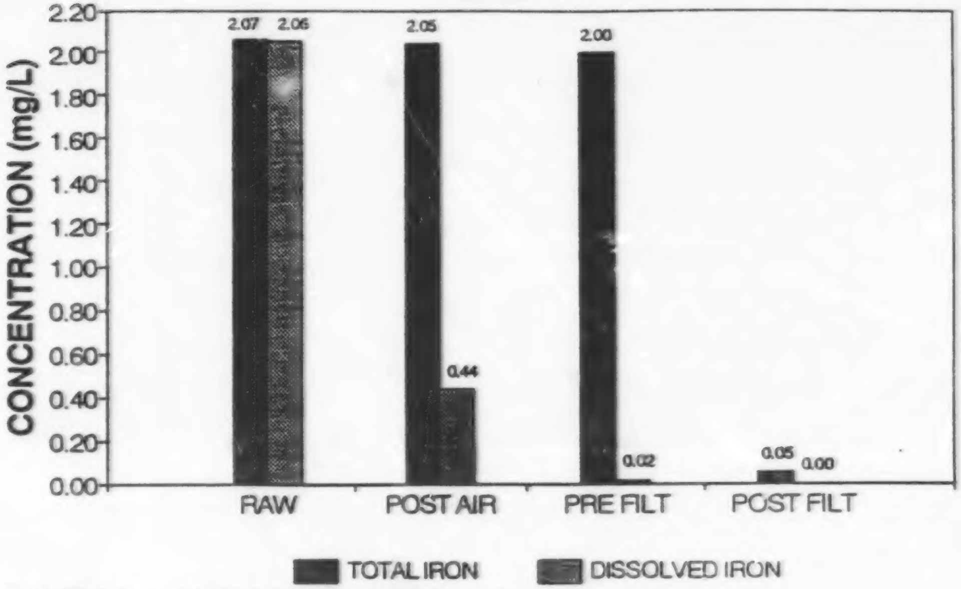

FIGURE 3 CONTINUOUS OPERATION OF A - O(ClO_2) - F PROCESS TRAIN: IRON RESULTS

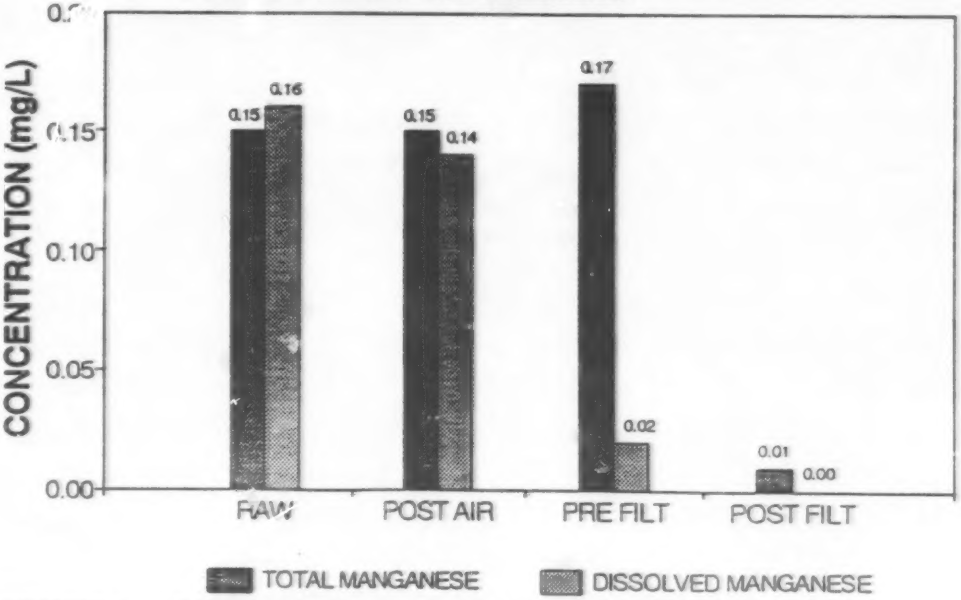

FIGURE 4 CONTINUOUS OPERATION OF A - O(NaOCl) - F PROCESS TRAIN: MANGANESE RESULTS

filter-applied water (reaction time = 2 minutes). The filtration rate was 4.25×10^{-3} m/s.

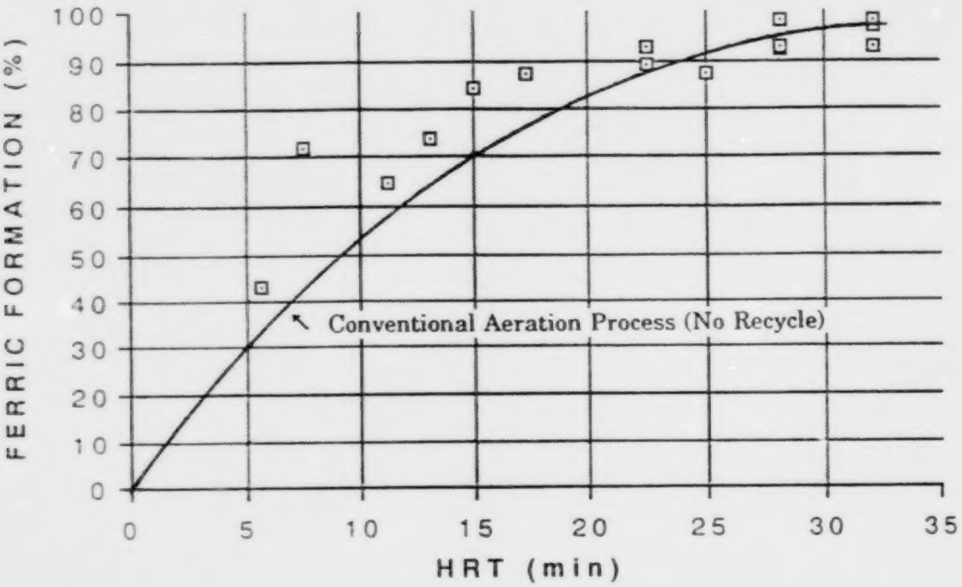

FIGURE 5 IRON(II) OXIDATION AT pH = 7.6 / 20% RECYCLE RATIO

Figures 6 and 7 illustrate the performance profile of this train for iron and manganese removal. About 96% of iron was oxidized in the aeration vessel. About 98% of the iron was removed in the sand filter.

About 95% of manganese(II) was oxidized following ClO_2 addition at 6 x stoic. About 94% of manganese was removed in the sand filter. The concentration of total iron and manganese in the treated water were 0.04 mg/L and 0.01 mg/L, respectively.

The results of this study showed that recirculating 20% of the effluent from the diffused aeration vessel did not improve iron or manganese oxidation.

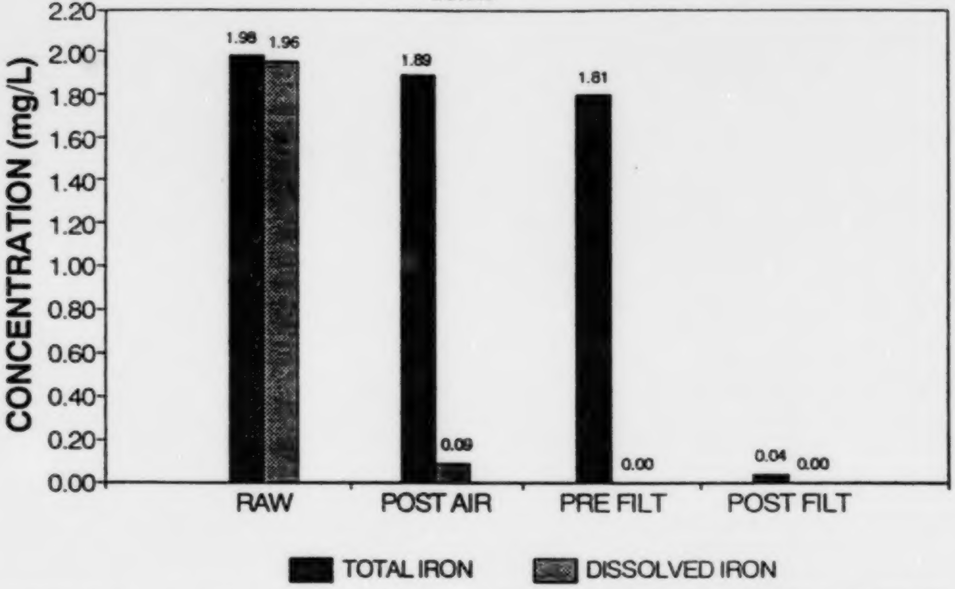

FIGURE 6 A(RECYCLE) - O(ClO_2) - F PROCESS TRAIN: IRON RESULTS

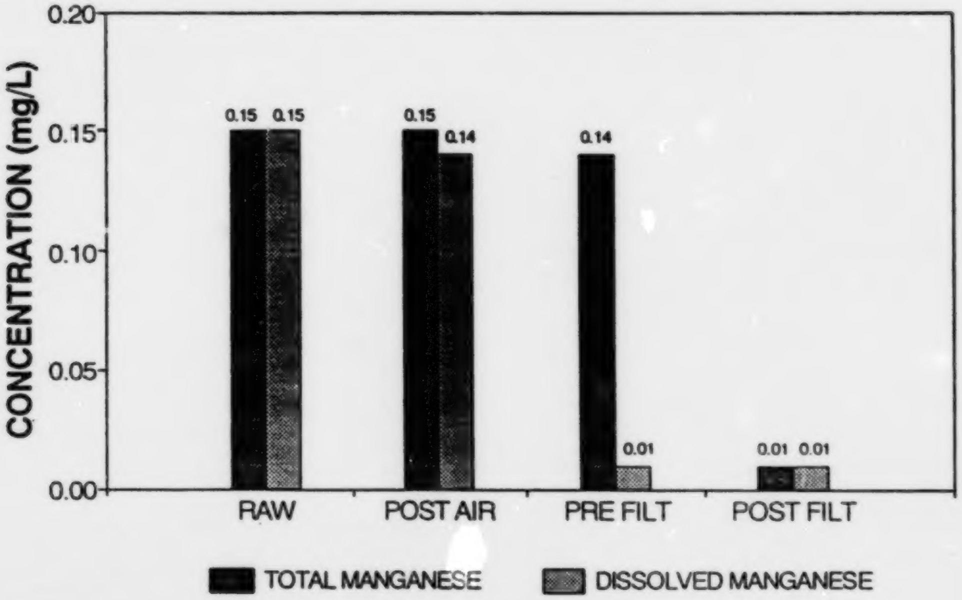

FIGURE 7 A(RECYCLE) - O(ClO_2) - F PROCESS TRAIN: MANGANESE RESULTS

7.0 PILOT SCALE TREATABILITY STUDIES: ENHANCED AERATION PROCESS II - SLUDGE ADDITION

7.1 Diffused Aeration Process - Sludge Addition

Fourteen runs were completed to evaluate the rates of oxidation of iron and manganese in the diffused aeration vessel, when added sludge maintains a high concentration of iron(III) in the vessel. This work assessed if the rates of oxidation of iron and manganese were accelerated by increasing total iron by up to 500%, i.e. sludge addition factor (SAF) = 5, in the diffused aeration vessel. Sludge was generated by operating, at night, the diffused aeration - direct contact sand filtration process train. It consisted, therefore, mainly of iron(III) oxides.

The concentration of total iron in the raw groundwater varied between 1.99 mg/L and 2.12 mg/L. The concentration of total manganese in the raw groundwater varied between 0.12 mg/L and 0.17 mg/L.

The data collected at a pH of 7.6 and SAF of 4-7 has been plotted and presented in Figure 8. For better illustrative purposes, the data collected previously during the conventional diffused aeration process (SAF = 0) has also been plotted (overlay plot) to present the similarity in oxidation rate profiles.

About 92% of iron(II) was oxidized at a pH of 7.6, a SAF ~ 5, and a hydraulic retention time greater than 22 minutes. For comparison, the conventional diffused aeration process achieved similar iron oxidation results at the identical pH and comparable retention time.

Manganese(II) was not oxidized within experimental error, in the diffused aeration vessel under any of the experimental conditions subjected.

In a few experimental runs, outside the original mandate of this study, a substantially large quantity of iron(III) was recirculated back to the diffused aeration vessel. Sludge addition factors of 0 to 59 were experimented with, at a pH of 7.6 and a hydraulic retention time of four minutes. Figure 9 presents ferric formation as a function of SAF at these conditions.

At a SAF = 59, almost complete iron oxidation (> 90%) was recorded. In

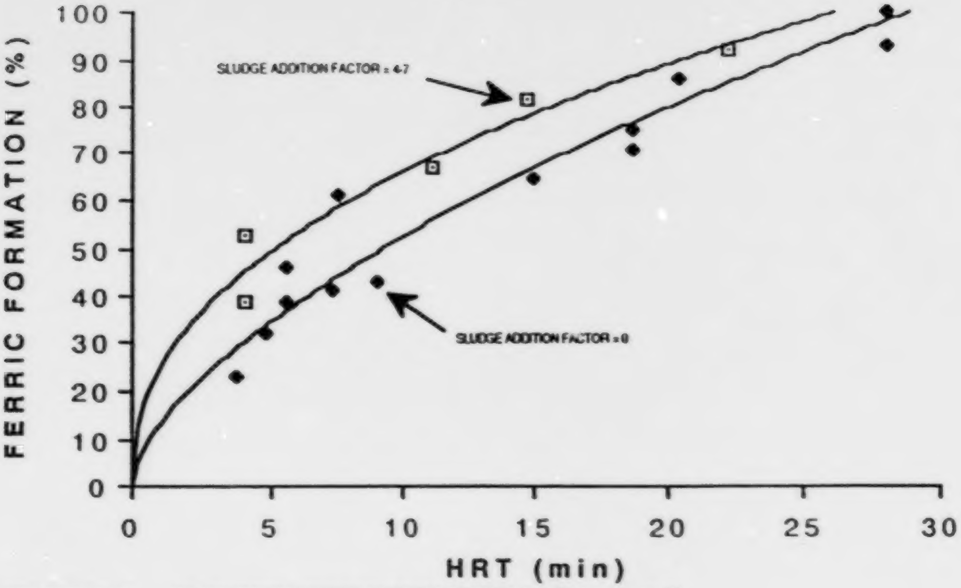

FIGURE 8 IRON(II) OXIDATION FOR SAFs = 0; 4-7

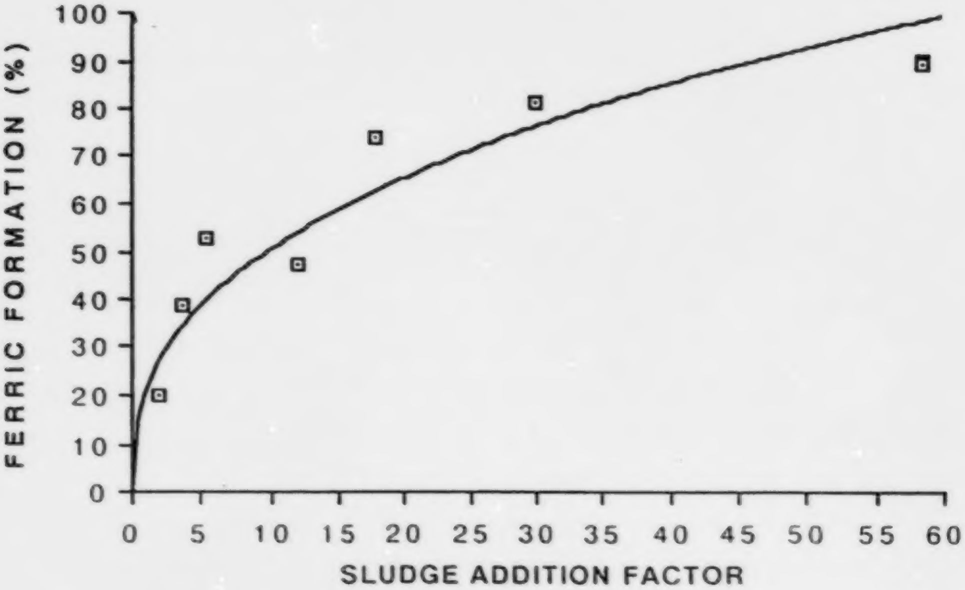

FIGURE 9 IRON(II) OXIDATION FOR SAFs = 0-59

contrast, manganese(II) was not oxidized in the diffused aeration vessel, for any SAF.

Hence, sludge addition, when SAF = 59, decreased the hydraulic retention time required for virtually complete ferric formation, from approximately 28 minutes to four minutes.

Three main conclusions were drawn from the performance evaluation of the diffused aeration - sludge addition process. These were:

1. For sludge addition factors less than 7, the design/operation requirements for iron(II) oxidation were similar to those determined during the conventional diffused aeration process. Similarly, the oxidation of manganese(II) was not promoted even at a SAF of 7.
2. For a sludge addition factor of 59, a hydraulic retention time of four minutes was required to oxidize > 90% of iron(II). Recirculation of the sludge did not, however, promote manganese(II) oxidation.
3. The addition of a chemical oxidant is required, following aeration, to oxidize manganese(II).

7.2 Diffused Aeration - Sludge Addition - Chemical Oxidation - Direct Contact Sand Filtration (A(Sludge) - O - F) Process Train

The performance of the diffused aeration - sludge addition - chemical oxidation - direct contact sand filtration process train was operated continuously to assess the overall performance of the process train and mass storage capacity of the sand filter.

The performance profile of this process train for iron and manganese is illustrated in Figures 10 and 11, respectively.

The mean concentrations of total iron and manganese in the raw groundwater were 2.07 mg/L and 0.17 mg/L, respectively. After the sludge was added (SAF = 7.4) to the raw groundwater, the mean concentrations increased from 2.07 mg/L to 15.37 mg/L for iron and 0.17 mg/L to 1.19 mg/L for manganese.

Sludge, continuously generated nightly during the operation of the diffused aeration chemical oxidation - direct contact sand filtration process train, had a high content of iron(III) and manganese(IV) oxides.

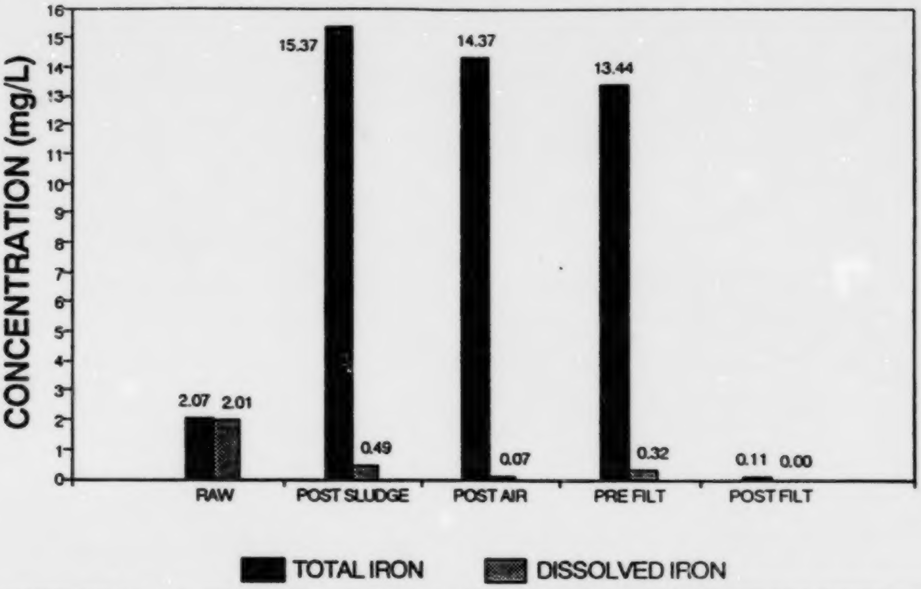

FIGURE 10 A(SLUDGE) - O(ClO_2) - F PROCESS TRAIN: IRON RESULTS

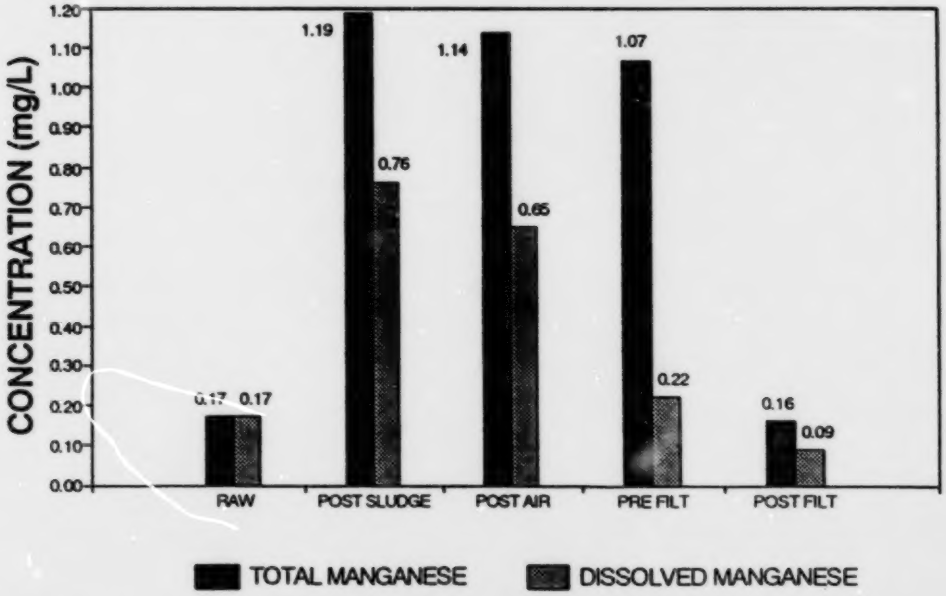

FIGURE 11 A(SLUDGE) - O(ClO_2) - F PROCESS TRAIN: MANGANESE RESULTS

Rapid reduction of manganese(IV) to manganese(II) was observed immediately following sludge addition in the diffused aeration vessel influent. Correspondingly, rapid oxidation of iron(II) to iron(III) was observed, prior to aeration. Sludge addition resulted in the oxidation of (2.01 mg/L - 0.49 mg/L =) 1.52 mg/L of dissolved iron (mean ferric formation = 76%) prior to aeration, and in the reduction of (0.76 mg/L - 0.17 mg/L =) 0.59 mg/L of manganese. This increase in dissolved manganese(II) concentration increased the chemical oxidant demand for ClO_2 in the filter-applied water for complete manganese oxidation and removal. However, the chemical oxidant dosage of 7 times the stoichiometric requirement of manganese(II) in the raw groundwater was left unchanged to demonstrate the effect of recirculating sludge to the diffused aeration vessel.

Remaining dissolved iron(II) was effectively oxidized in the diffused aeration vessel (mean ferric formation = 97%). Dissolved manganese(II) was incompletely oxidized by ClO_2 (mean manganic formation = 66%). The mean concentration of dissolved manganese(II) in the filter influent was 0.22 mg/L which exceeded the mean dissolved manganese(II) concentration in the raw groundwater of 0.17 mg/L.

Breakthrough of manganese was observed only two hours into the run; the total manganese concentration was 0.20 mg/L. Breakthrough of iron was observed eleven hours into the run. The mass storage capacity of the sand filter was equal to or less than 6.2 kg suspended solids/m^3 sand, of which $\leq$ 2.5 kg was Fe and $\leq$ 0.04 kg was Mn.

In conclusion, the performance of the diffused aeration - sludge addition - chemical oxidation - direct contact sand filtration process train was poor. This was attributed to two factors. These were:

1. The reduction of manganese oxides(IV) and the corresponding oxidation of iron(II) by these oxides in the raw groundwater prior to aeration defeats the purpose of using air to oxidize iron(II). Furthermore, the reduced manganese produced, demands a substantially higher dosage of the costly chemical oxidant, ClO_2, in order to enable the filter effluent to meet its iron and manganese objectives.

2. An unexpectedly high frequency of backwashes is required when sludge is recirculated to the diffused aeration vessel. Since the present process did not demonstrate any performance advantage over the conventional diffused aeration process, the requirements for frequent backwashes and for the installation of a sludge recirculation process cannot be substantiated.

8.0 PILOT SCALE PERFORMANCE EVALUATION OF RECOMMENDED PROCESS TRAIN: CONVENTIONAL DIFFUSED AERATION PROCESS

The diffused aeration - chemical oxidation (ClO_2) - direct contact sand filtration process train was selected for its good performance and simplicity over the enhanced aeration processes in which solids were recirculated to the diffused aeration vessel.

This recommended process train was operated continuously for seven days. The operating requirements for the A - O($ClO_{2,}$) - F process train were:

Diffused Aeration Vessel:	pH = 7.6 hydraulic retention time = 23 minutes
On-line Chemical Oxidant Addition:	oxidant type = ClO_2 oxidant dosage ($ClO_2 \rightarrow Cl^-$) = 7 x stoic reaction time = 2 minutes
Direct Contact Sand Filtration:	sand bed depth = 1.1 m sand effective diameter = 0.52 mm filtration rate = 5.3×10^{-3} m/s

The following points were sampled eighteen times during that period:

- Raw Groundwater (before aeration vessel)
- Post-Air (before on-line ClO_2 addition)
- Pre-Filt (after on-line ClO_2 addition)

The effluent from the process train (Post-Filt) was sampled seventy-eight times during that period.

The performance profile of the recommended process train is illustrated in Figures 12 and 13.

The mean concentrations of total iron and manganese in the raw groundwater

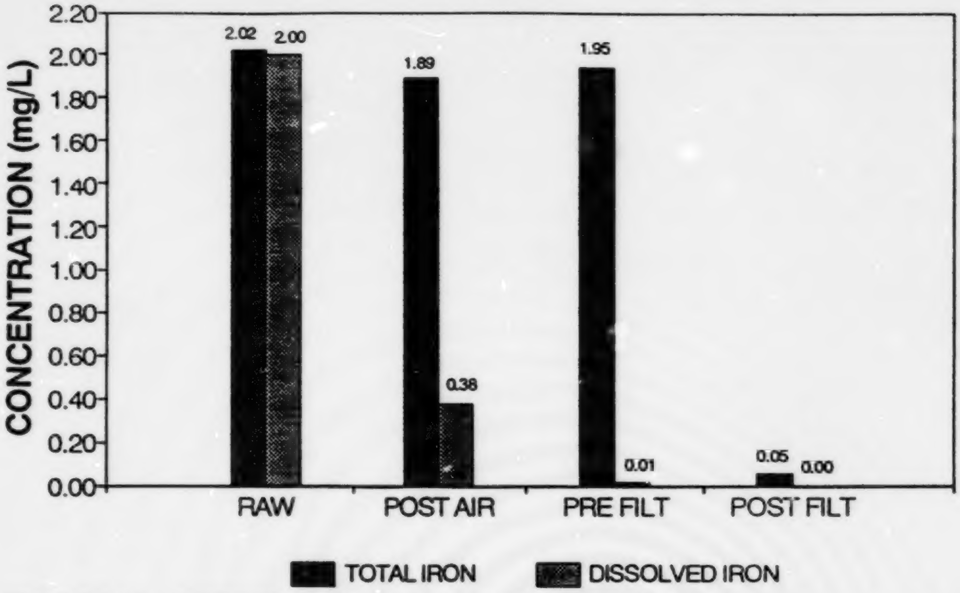

FIGURE 12 PERFORMANCE EVALUATION OF A - O(ClO_2) - F PROCESS TRAIN: IRON RESULTS

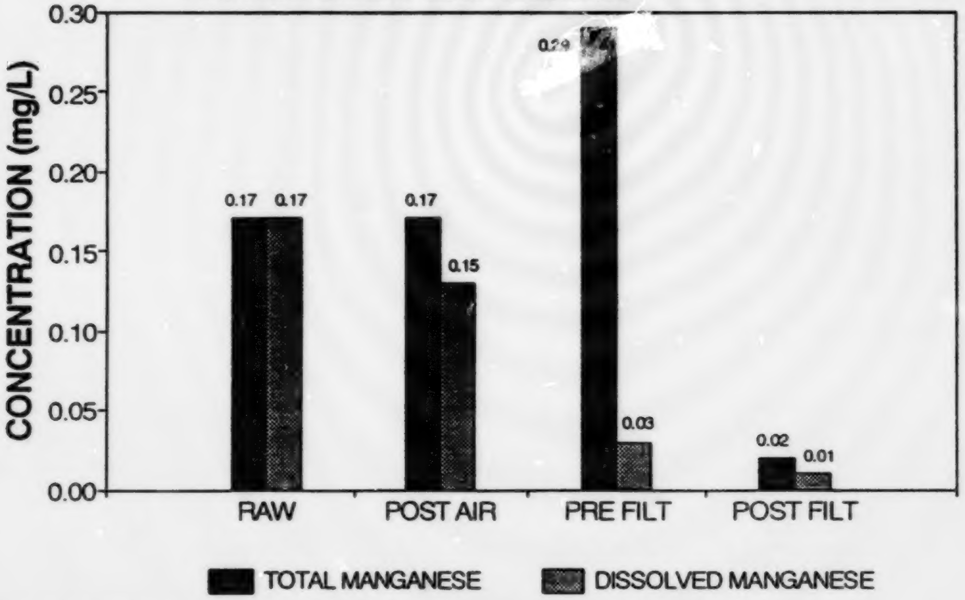

FIGURE 13 PERFORMANCE EVALUATION OF A - O(ClO_2) - PROCESS TRAIN: MANGANESE RESULTS

were 2.02 mg/L and 0.17 mg/L, respectively.

About 81% of iron(II) was oxidized in the diffused aeration vessel at a hydraulic retention time of 22 minutes and at a pH of 7.6. Manganese(II) was not oxidized, within experimental error, in the diffused aeration vessel.

The addition of ClO_2 at 7 x stoic, oxidized 82% manganese(II) and left a residual of 0.03 mg/L, in the filter influent.

Iron and manganese were effectively removed in the sand filter throughout the duration of the experimental run. The mean iron and manganese concentrations in the effluent of the process train were 0.05 mg/L and 0.02 mg/L, respectively.

9.0 CONCLUSIONS

This development and demonstration work focused on increasing the rates of oxidation of iron and manganese in a diffused aeration vessel, through the introduction of a solids-bearing stream to the diffused aeration vessel.

Two processes were investigated, and compared to a conventional co-current diffused aeration - direct contact sand filtration process train. These were: 1) a continuous recycle loop process, where a fraction of the aeration vessel effluent was recycled back to the vessel's influent line; and 2) a sludge recirculation process, where sludge, collected from the sand filter backwash water, was recirculated to the diffused aeration vessel influent line.

Based on the performance evaluations of the three process trains, the following conclusions were formulated:

1. Diffused aeration of the groundwater is technically feasible, and was found effective in oxidizing iron(II) to iron(III), at a pH of 7.6 and a hydraulic retention time of approximately 23 minutes.
2. Diffused aeration was not found effective for the oxidation of manganese(II) for pH values equal to or below 7.8. Hence, the addition of a chemical oxidant is required, following aeration.
3. Chlorine dioxide was found effective for the rapid on-line oxidation of manganese(II) to manganese(IV).

4. The diffused aeration - on-line chlorine dioxide addition - direct contact sand filtration process train was found highly effective in removing iron and manganese below drinking water objectives.
5. The continuous recycle of 20% of the aeration vessel effluent to its influent point did not promote iron or manganese oxidation in the diffused aeration vessel. The design/operating requirements of the continuous recycle loop process were equivalent to those of the conventional diffused aeration process, for recycle ratios of 20% or less.
6. The recirculation of iron(III) sludge to the aeration vessel influent, for total iron concentration increases of up to 700% in the groundwater undergoing aeration, did not increase the rates of oxidation of iron or manganese. The design/operating requirements of the sludge addition process were equivalent to those of the conventional diffused aeration process, for sludge addition factors of seven or less.
7. The recirculation of iron(III) and manganese(IV) sludge to the aeration vessel influent was found detrimental to the operation of an iron and manganese removal process train. Chemical reduction of manganese oxides and the corresponding oxidation of iron(II) in the raw groundwater, immediately prior to aeration, was observed, defeating the purpose of using air to oxidize iron(II). Furthermore, the reduced manganese produced exerted a substantially higher chemical oxidant demand in order to enable the treated water to meet its iron and manganese objectives. Early breakthrough of manganese oxides from the sand filter bed was observed, resulting in a substantial decrease in the maximum mass storage capacity of the bed.
8. A few additional runs, outside the original mandate of the study, were conducted during which large quantities of iron(III) sludge were recirculated to the diffused aeration vessel. SAF greater than 50, substantially increased the rate of oxidation of iron in the diffused aeration vessel; the hydraulic retention time required for virtual complete iron oxidation decreased to four minutes.

9. The selected process train was the diffused aeration - chemical oxidation - direct contact sand filtration process train. It was demonstrated most effective in removing iron and manganese from the groundwater without requiring the addition of coagulant, flocculant or aqueous pH conditioner. The process train minimizes the number of unit processes required for iron and manganese removal and minimizes sludge production. The optimum design/operating parameters, based on the pilot scale process train treatability studies, are presented in Table 3.

TABLE 3 RECOMMENDED PROCESS TRAIN: DIFFUSED AERATION - CHEMICAL OXIDATION - DIRECT CONTACT SAND FILTRATION

PROCESS ELEMENT	DESIGN/OPERATING PARAMETERS
1. Diffused Aeration Vessel	Oxidation pH: 7.6 Hydraulic Retention Time: 22 minutes
2. Chemical Oxidation	On-line Addition (Reaction Time ≤ 2 minutes) Oxidant Type: ClO_2 Oxidant Dosage ($ClO_2 \rightarrow Cl^-$): 7 x stoic
3. Direct Contact Sand Filtration	Sand Bed Depth: 1.1 m Sand Effective Diameter: 0.52 mm Filtration Rate: 5.3×10^{-3} m/s

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2. "Aquifer Decontamination for Toxic Organics: The Case Study of Ville Mercier, Québec", The SNC Group. 1992 (unpublished).

BIOGRAPHICAL SKETCH - MARC HALEVY

Marc Halevy is a chemical engineer at the Wastewater Technology Centre, responsible for the development, evaluation and demonstration of advanced oxidation reduction technologies, aimed at the effective treatment of refractory industrial wastewaters; and of metal, e.g. iron, manganese, removal and sequestration processes, aimed at drinking water, site remediation and industrial applications. Previous experience at The SNC Group (Montréal) also includes the conduct of the field segment of the NATO/CCMS Ville Mercier (Québec) site remediation study, and the research and development of new processes in synthetic fuel production and heavy oil upgrading.

19.0

OPTIONS FOR CLEANING UP SUBSURFACE CONTAMINATION AT ALBERTA SOUR GAS PLANTS

by
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ABSTRACT

At the conclusion of two major phases of a study on "Subsurface Treatment Technologies for Alberta Sour Gas Plants" a candidate site was selected for remediation technologies demonstration project. This plant has an extensive groundwater monitoring network in place (over 80 monitoring wells), monitoring records for a period exceeding 10 years, ten recovery wells with aquifer test data and four reinjection wells.

Hydrogeological exploration programs determined the presence and delineated the plume of free phase natural gas condensate. Associated with the free phase is dissolved phase plume with BTEX concentrations up to 86 mg/L. Groundwater in the contaminated area also contains dissolved diethanolamine (DEA), nitrogenous compounds that are possible products of amine degradation and naphthalene. Iron concentration within this plume are variable and may exceed 10 mg/L.

Aquifer remediation efforts at the site began in 1990 with completion of a four month pilot test. Recovery wells were installed and operated to determine expected yields, monitor aquifer response and define the hydrochemical nature of contaminated groundwater. Recovered groundwater was treated using a pilot-scale air stripping system with pre-treatment for iron, manganese and hardness. Dual pump system, water depression and free product skimmers were installed in the wells and tested.

This plant offers opportunities for demonstration of the following technologies:

- Remediation of free condensate in the unsaturated zone of permeable sediments using enhanced soil vapour extraction, with off-gas treatment,
- Remediation of groundwater contaminated by dissolved volatile organic compounds in permeable sediments using pump-and-treat, soil vapour extraction, biological treatment and air sparging,
- Treatment of volatile hydrocarbons dissolved in groundwater by enhanced air stripping with off-gas treatment, and
- Remediation of process chemicals dissolved in groundwater in permeable sediments using pump-and-treat with advanced oxidation processes.

OPTIONS FOR CLEANING UP SUBSURFACE CONTAMINATION AT ALBERTA SOUR GAS PLANTS

1. INTRODUCTION

Recognizing the potential impacts of sour gas plant operations on the subsurface environment, the Canadian Petroleum Association (CPA) and Environment Canada have launched this multi-phase study focusing on demonstrating remedial technologies for soil and groundwater contamination at these facilities. The first phase was completed in 1990, and consisted of a comprehensive review of all soil and groundwater monitoring data submitted to Alberta Environment by sour gas plants in accordance with the Clean Water Act (1971). The review indicated that all but one of 45 sour gas plants reviewed exhibited some form of impact on soil and groundwater quality (CPA, 1990; Hardisty et al, 1990). The study identified the most frequently occurring contamination situations at 45 plants, and classified them according to sources and types of contaminants, and the hydrogeological characteristics of the geologic host. The Phase I report has been published by the CPA, and is now available.

The next phase of the study consisted of a detailed review of available subsurface remedial technologies which could be applied to the specific problems identified in Phase I. For this phase of the work, an international team of experts was brought together to assess established and innovative technologies, and recommend those with the most potential for dealing with the types of contamination situations prevalent at sour gas processing facilities in Alberta. A parallel goal was to identify new and innovative technologies which show promise for application at these sites, and are worthy of further field or bench-scale testing.

The results of this (Phase IIA) technology study, (CPA, 1991a), available through the CPA, provide initial guidance for implementation of subsurface remediation technology demonstration projects. In tandem with this study of appropriate remedial technologies, the task of soliciting formal support for the implementation of field demonstration projects from plant operators in Alberta (Phase IIB) was undertaken by the steering committee. Phase I of the study identified five sour gas plants in Alberta whose subsurface contamination situations and level of site characterization were suitable for field demonstration purposes. The operators of these plants were approached; and the present level of site characterization and remediation at each assessed (CPA, 1991b).

The present phase of work, described in this paper, involves matching the recommended technologies from Phase IIA with sites identified in Phase IIB. One of the most important goals of the overall project is to provide opportunities for research into subsurface remediation systems suitable to the unique conditions and contamination situations found at sour gas plants. The results of the project should also be of benefit to other petroleum industry installations in Alberta.

2. STUDY METHODOLOGY

The methodology described in this section involves a systematic ranking of the technology/situation combinations available at the five candidate sites.

As a first step, a brief preliminary review of all the available contamination situations from among the five candidate sites was made, based on information from previous phases of the project. For each of the situations, a brief discussion of technical and economic suitability for remediation demonstration is made. Considerations included:

- level of current remedial activity
- level of present site characterization
- logistical concerns
- level of understanding of the problem
- level of anticipated technical difficulty in achieving remediation
- anticipated economic implications of the above

For each of the situations, a set of recommended technologies (established and innovative) has been identified in the Phase IIA report. The technology recommendations are reviewed briefly, and the important prerequisites to their implementation discussed. Such prerequisites include specific site characterization needs, and the presence of other remedial systems (for example, to test an advanced oxidation system to treat groundwater, a working groundwater extraction scheme must be in place).

From among the situation/technology combinations present at the five candidate sites, the most suitable for demonstration were determined, based on the following criteria:

General Criteria:

- The general level of site characterization and of the specific contamination situation. This is reflective of the level of understanding of the subsurface conditions at the site, and the behaviour, distribution and levels of target contaminants.

- Representativeness of the contamination situation of typical conditions at Alberta sour gas plants. The Phase I study provided a detailed picture of the common subsurface conditions and contaminant types encountered at ASGP's. To be of most benefit to the industry as a whole, demonstration sites should be generally reflective of these conditions.

- Logistics, access, and other intangibles.

Technology-Dependent Criteria

- The level of additional site characterization required to successfully demonstrate the particular recommended technology. Different technologies will require different types of data for their design. For instance, implementation of enhanced soil vapour extraction requires detailed information on the physical properties (permeability, thickness) of the unsaturated zone and the vapour phase behaviour of the contaminants.

- The presence at the site of the required prerequisite remedial technology or technologies. For instance, demonstration of air-stripping treatment systems requires a working pump-and-treat system to be in place; off-gas treatment demonstration requires a soil vapour extraction system or air-stripping system to be in place.

- Practical application of the technology to the problem;

- The anticipated level of effort required to put all prerequisites in place and complete necessary site characterization.

The results were assembled in a ranking matrix, showing how the combinations were rated on each criteria. For simplicity, ranking is done on a three-tiered basis. For instance, general level of site characterization is specified as low, moderate or high (1, 2 and 3 respectively). These levels are assigned purely on a relative basis, within the set of five candidate plants being considered. These ratings have no other significance, and should be taken in the context of suitability for demonstration of remedial technologies only. The highest scoring combinations (site - technology matchups) were identified.

For each of the top ranked technology - situation combinations, a conceptual remedial plan was developed.

First, site characterization and field data collection activities required for detailed design of the system were identified. An approximate cost was then estimated for the work. In the same way, remedial prerequisites were also identified and rough cost estimates prepared. The result of this activity is to provide, for each possible demonstration project, the technical requirements before demonstration can proceed, and an approximate cost to complete the work.

Second, for each demonstration opportunity, a conceptual design for remedial demonstration program implementation was developed. The designs are based on available information on the site, and take into account the identified site characterization and other requirements.

The design approaches prepared include:

- data requirements, preliminary testing and evaluation program
- pilot phase implementation

- basic design of overall remedial system
- identification of associated concerns such as disposal of produced water and wastes, permitting, practical problems (pipeline crossings, winter operation);
- preliminary cost estimate for the program
- use of existing equipment and infrastructure

As a final step, the recommended demonstration opportunities are then compared and contrasted with respect to their technical and economic merits. Final prioritization is necessarily left to the funding agencies themselves; for example, some may be more interested in certain types of problems or technologies than others.

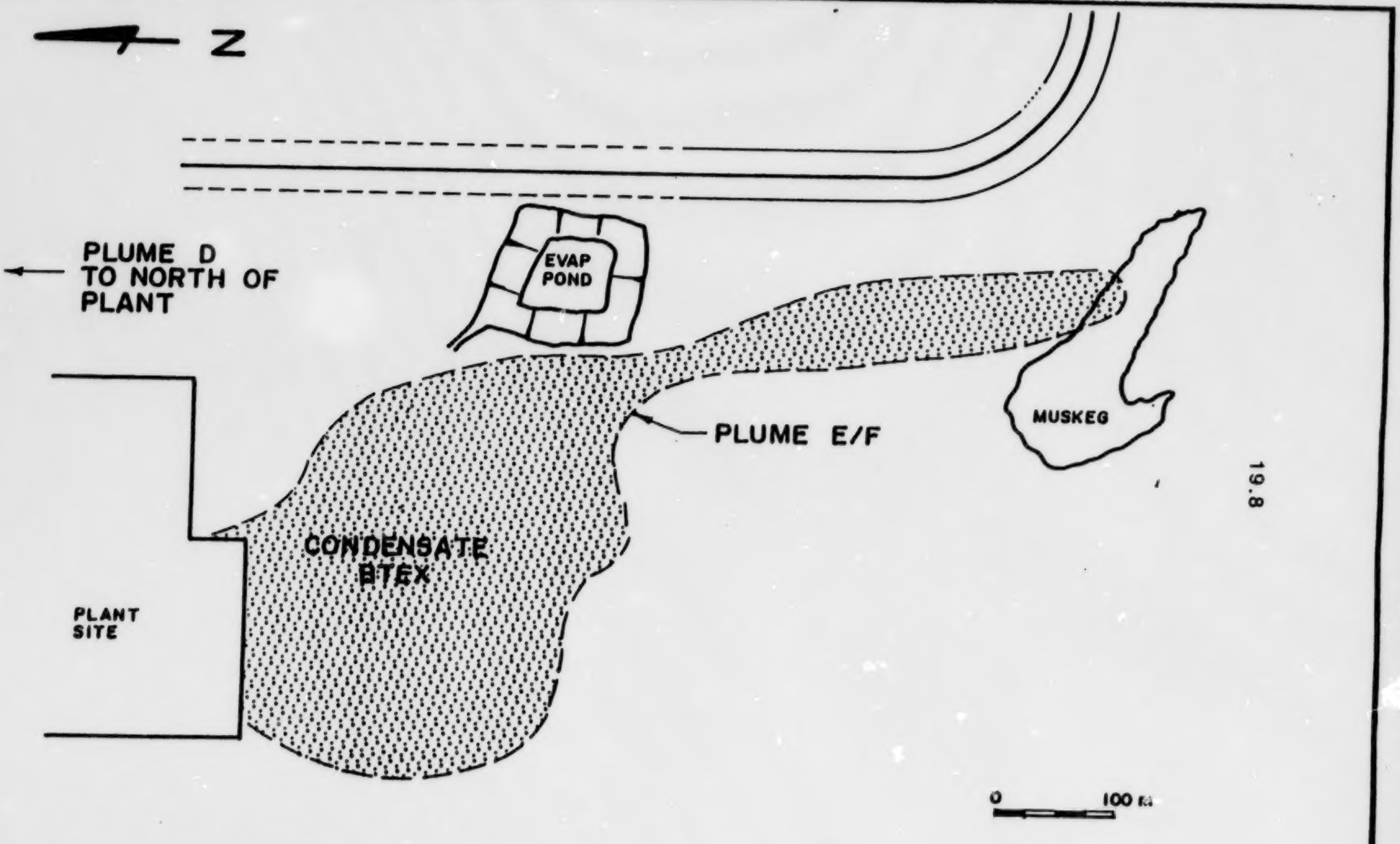
3. CONTAMINATION SITUATIONS AT CANDIDATE SITE

The contamination situations present at the five candidate sites were reviewed as part of the Phase IIB report (CPA, 1991b). In this section, the contamination situations in question are discussed in terms of their general suitability for remedial demonstration. For detailed information on each of the situations, refer to CPA (1991b).

PLANT B:

Groundwater monitoring has been underway at this site since 1978, and over the ensuing years two main zones of groundwater contamination have been identified; a minor plume to the north of the plant, and a major plume of free condensate and dissolved organics to the south (Figure 3.1). The plant operator has expended considerable effort over the past few years in delineating the extent of the southern plume, and characterizing hydrogeological conditions at the site. At present, a large-scale groundwater remediation program is underway at the site, aimed at controlling further off-site migration of contaminants and dealing with mobile LNAPL. In general, the level of site characterization at this site is the highest of all the candidate plants. More piezometers have been installed, more long-term aquifer tests conducted, more chemical characterization of contaminants undertaken, and more detailed geological testing performed.

This plume (E/F) constitutes the major contamination situation at the plant. The plume of free phase natural gas condensate is estimated to cover approximately 65,000 m^2, with apparent thicknesses of product in monitoring wells reaching as much as 1.5 m. Associated with the free hydrocarbon plume is a dissolved phase plume, in which total BTEX concentrations average about 10 to 15 mg/L. Groundwater in the contaminated area is also characterized by levels of iron fluctuating from 10 to 0.1 mg/L. Within the condensate plume, groundwater has also been found to contain small concentrations of Diethanolamine (DEA), and elevated levels of other nitrogenous compounds (signalled by elevated levels of TKN) believed to be amine degradation products. Low levels of naphthalene have also been detected. Geologically, the plume is hosted in relatively permeable sand and gravel glaciofluvial material to the north, and in fractured bedrock to the south. The gravels overlie and are in hydraulic connection with the fractured bedrock. Seasonal groundwater surface fluctuations of up to 3 m per year have resulted in a significant smearing of condensate in the unsaturated zone. Accordingly the contamination situation can be classified as T1A (condensate and associated dissolved products in high K surficial material), R1/R2 A (condensate and associated dissolved products in fractured bedrock), and S1A (condensate in unsaturated zone high K materials).


N
PLUME D
TO NORTH OF
PLANT
EVAP
POND
PLANT
SITE
CONDENSATE
BTEX
PLUME E/F
MUSKEG
0
100 m

PLANT B
SITE SKETCH SHOWING
MAIN CONTAMINATION SITUATIONS

BY: M.T.
DATE: FEB./92
APPROVED:
FIGURE: 3.1

Site characterization work on this plume has been extensive and detailed, and has been implemented to provide key data for the design and operation of remedial activities presently underway. The plume area has been delineated with over 90 monitoring wells. Two separate soil vapour surveys have been completed to delineate hydrocarbon contamination. Several detailed aquifer tests were completed, including an extended 120 day pumping test from one of the ten groundwater recovery wells on-site.

Remediation efforts at the site began in 1990, with completion of a four month pilot test. Groundwater recovery wells were installed and operated to determine expected pumping rates, track aquifer response, and determine the hydrochemical nature of groundwater extracted. Recovered groundwater was treated using a pilot-scale air-stripping system, with pre-treatment for iron, manganese and hardness, and granular activated carbon polishing. Pumps installed in the wells tested the application of dual pump systems incorporating water table depression pumps and free product skimmers. The test well, completed in bedrock, was found capable of a sustained yield of about 20 igpm, and produced water with average BTEX concentration of about 10 mg/L. Air stripping was found to be over 99% effective in removing dissolved BTEX from produced groundwater. Free product response was found to be slow, but perceptible. The pumping well radius of influence was determined to be at least 100 m. Based on these findings and the monitoring of over 30 piezometers during the extended test, a hydrogeological model was developed, and an optimum design for the full-scale system determined.

In 1991, the full-scale design for a pump-and-treat system was implemented and the system became operational. The final system was designed to control further off-site migration of the contaminants, and make a start at removing mobile free condensate collecting in wells. The system is intended to operate in conjunction with technologies designed to remove the bulk of immobile condensate from the unsaturated zone. At present, soil vapour extraction is the leading choice. The system consists of 5 recovery wells, each winterized and tied into the treatment centre with buried insulated lines to allow year-round operation. The treatment centre pre-treats water for iron, manganese and hardness, before passing it through an air-stripper. At present, off-gasses from stripping are vented to atmosphere. Treated water is reinjected into the gravel unit upgradient of the plume.

This plume (E/F) offers opportunities for demonstration of technologies which require a working pump-and-treat system to be in place as a prerequisite. This would include such techniques as in-situ bioremediation, advanced oxidation treatment of groundwater, and off-gas treatment from air-stripping. The extent of free condensate contamination in the unsaturated zone makes this site suitable for demonstration of soil vapour extraction (SVE), enhancements to SVE, and consequent off-gas treatment systems.

Demonstration of technologies for dealing with free and dissolved phase condensate in the subsurface could proceed at this site without substantial additional general site characterization. Depending on the technology selected, some specialized site characterization may be required. Demonstration of technologies for treating produced groundwater or off-gases from air-stripping would not require additional site characterization.

4. ASSESSMENT OF TECHNOLOGY - SITUATION MATCHES

Each of the contamination situations characteristic for plume E/F were reviewed in detail, classified, and the appropriate technology recommendation assigned, based on the results of Phase IIA. For each contamination situation, both established and innovative technology recommendations are provided, and comments on the general applicability provided.

In each case, as per the recommendations of the expert team assembled for Phase IIA, a general remedial approach is provided. Often this involves the coupling of several different technologies. For instance, remediation of condensate in surficial glaciofluvial deposits would require pumping of groundwater to control plume migration, skimming of mobile free product, combined with soil vapour extraction to remove the bulk of residual condensate. In-situ bioremediation can be used as a final polishing step if required.

For treatment technologies in the areas of off-gas treatment and treatment of groundwater after extraction, ranking was done separately. These technologies can only be used and demonstrated in conjunction with systems designed to remove contaminants from the subsurface. For instance, off-gas technology can be demonstrated only where a working soil vapour extraction program is underway, or where an air-stripper is operational. Similarly, for groundwater treatment technologies such as advanced oxidation or enhanced air-stripping to be demonstrated, groundwater recovery wells must be operational. These types of technologies are ranked and discussed based on two scenarios: the first, that an existing extraction system is working on the site, to which the treatment technology can be coupled; the second, that the treatment technology can be demonstrated as part of a larger demonstration project which would include installation of the necessary extraction systems.

5. DEMONSTRATION OPPORTUNITIES

5.1 DEMONSTRATION OPPORTUNITY 1: REMEDIATION OF FREE CONDENSATE IN THE UNSATURATED ZONE OF PERMEABLE SEDIMENTS USING ENHANCED SOIL VAPOUR EXTRACTION, WITH OFF-GAS TREATMENT

5.1.1 Research Value

There was only one example of condensate contamination in relatively permeable surficial materials at the candidate sites, this exists at plant B. However, the one example of this type of problem is considered an ideal demonstration opportunity as the site has been well characterized, and remedial activities are well advanced. The opportunity to make use of waste heat from the plant to enhance soil vapour extraction (SVE) is also available.

Technical feasibility of this demonstration is also good, as soil vapour extraction techniques are most effective in higher permeability materials. The presence on-site of a working pump-and-treat system will provide groundwater surface maintenance, an important component of SVE in areas of fluctuating seasonal water tables.

The plume in question is large, and relatively well delineated. This allows the location of a demonstration pilot project to be chosen without too much additional effort or drilling. Data are available on the physical and chemical properties of the condensate, and two soil vapour surveys completed at the site provide initial reference data for project design.

Implementation of a standard soil vapour extraction demonstration project at this site would provide valuable data on the effectiveness of this widely used method on unrefined natural gas condensates - an area where little work has been done to date. Such research would be of particular value to the natural gas processing industry in Alberta, as situations of this type have been found to exist at several other sour gas plants in the province.

The site also offers a unique opportunity to demonstrate and assess the effectiveness of various enhancements to SVE. The plant produces large quantities of waste heat and steam, which may be harnessed, at relatively low cost, to improve the volatilization rate of organic chemicals in the subsurface. In addition, the concept of bioventing could be examined at this site. Previous studies conducted by the plant operator have identified the presence in the subsurface of naturally occurring microorganisms capable of degrading condensate. Results of this type of research would be of interest to a wide variety of organizations, within and outside of the natural gas industry.

5.1.2 Conceptual Design

The design of this demonstration project should be based on the premise that other technologies or modifications can be coupled with it, either from the start, or at a later date. In particular, the operation of an SVE system at this site allows simultaneous demonstration of SVE enhancement techniques (waste heat injection, bioventing), and SVE off-gas treatment (fluid knockout, flaring, catalytic oxidation). The design of the project should allow rapid and easy addition of one or more of these complementary technologies.

For these reasons, the chosen area should be as close to the plant as possible (to reduce distances from potential waste-heat sources), and close to the flare stack (to allow for eventual coupling of off-gas collection with existing flaring system). A location somewhere in the vicinity of RW-10, part of the existing pump-and-treat system, would provide some level of seasonal groundwater surface level control.

The pre-pilot test described above should be followed by analysis of available data to determine spacing of extraction points and passive air inlets. The 2 to 3 metres of till at surface should provide an ideal cap over the area, helping to ensure horizontal flow of air.

A demonstration project may involve a network of up to 20 extraction points, connected by manifolds to blowers. Collection lines should be fitted with liquid knockouts, as free condensate may be expected to condense at surface. The system can be winterized by burying all lines and housing all surface equipment in insulated heated buildings. This, however, would add significant expense to the project. One alternative is to operate the system only during the warmer months of the year, when volatilization rates are highest.

For research purposes, the system should be well instrumented, and equipped with a number of sampling and observation points. These should include soil gas monitoring wells completed at different depths and locations around the site. These could be fitted with soil gas sampling ports (to which a field-portable GC could hook-up and collect vapour) and sensitive pressure gauges. Extraction wells should be fitted with air-velocity meters to calculate air flow rates, and sampling ports to allow measurement of off-gas hydrocarbon concentrations.

As the site is highly contaminated, there is a good opportunity for demonstration of off-gas treatment technologies. The established technologies recommended in the Phase IIA report were liquid knockout and catalytic oxidation for high vapour concentrations, such as would be present in such an SVE scheme. Catalytic oxidation systems could be readily fitted to the outlet of the system described.

Of the innovative technologies, the use of flaring systems already on-site at most gas plants was recommended in the Phase IIA report. Feeding off-gas vapours into the plant's flare system would require detailed engineering in consultation with plant engineers. To eliminate problems associated with mingling the streams together before combustion, one solution may be to pipe off-gasses separately up the stack, and discharge them into the existing pilot flare. These and other design details will have to be finalized during the project design phase.

5.2 DEMONSTRATION OPPORTUNITY 2: REMEDIATION OF GROUND-WATER CONTAMINATED BY CONDENSATE IN PERMEABLE MATERIALS USING PUMP-AND-TREAT, SOIL VAPOUR EXTRACTION, BIOLOGICAL TREATMENT AND AIR SPARGING

5.2.1 Research Value

There was only one example of condensate contamination in relatively permeable surficial materials at the candidate sites, as described in demonstration opportunity #1, above (plant B). However, the one example of this type of problem is considered an ideal demonstration opportunity as the site has been well characterized, and remedial activities are well advanced. In addition, preliminary studies of the suitability of in-situ bioremediation have also been completed at this site.

The existing pump-and-treat system at the site is also equipped with injection wells, into which treated water is disposed. The injection wells are completed in the same formation from which contaminated water is drawn, setting up a flushing cycle. In-situ bioremediation requires establishment of just such a system to deliver oxygen and nutrients to bacteria. Presence of this infrastructure on-site reduces the amount of preliminary work required to implement an in-situ bioremediation demonstration project.

This demonstration opportunity is made significant by the fact that a working pump-and-treat system has already been installed at this site, consisting of recovery wells, free product skimming, and treatment of dissolved hydrocarbons in produced water by air-stripping. Phase IIA recommended that this type of situation would best be dealt with using a combination of techniques, beginning with the pump-and-treat approach described, and following it with SVE and eventually in-situ bioremediation as a polishing step. As the water table is lowered by pumping, LNAPL trapped in the unsaturated zone becomes exposed to air-flow and may be removed by SVE. Coupling of SVE with the existing pump-and-treat system has been discussed in demonstration opportunity # 1, above.

It is felt that one of the chief research opportunities provided here is the detailed study of the effectiveness of an existing pump-and-treat system on the contaminant plume, and of the successful coupling of two very different techniques (SVE and pump-and-treat) to provide maximum benefit.

The site also offers a unique opportunity to demonstrate the use of in-situ bioremediation for dealing with condensate contamination. Such a program would be of interest to all workers interested in the application of biological techniques in cooler climates.

5.2.2 Conceptual Design

The general approach to the recommended demonstration program is the coupling of various complementary techniques to deal with the common problem of light hydrocarbon contamination in shallow permeable aquifers. The opportunity described consists of taking an existing pump-and-treat system at a well characterized site, and adding soil vapour extraction, and then in-situ bioremediation to remediate the immobile residual contamination which a pump-and-treat system will leave behind. Demonstration of air-sparging or in-situ air-stripping is coupled to the bioremediation program as an alternate oxygen-delivery system. The benefits of air-sparging as a tool for volatilizing hydrocarbon contamination within the saturated zone may also be assessed.

The conceptual design for a SVE system to be coupled with the existing pump-and-treat scheme is discussed in demonstration opportunity #1, above. The implementation of an in-situ bioremediation system at the site would involve additional effort. The demonstration system should be designed to take advantage, as much as possible, of existing facilities on-site. These include the network of five operational recovery wells and four injection wells upgradient, and the treatment system which air-strips dissolved hydrocarbons from produced water. Use of these facilities will reduce overall project costs.

In-situ Bioremediation Component

The first design steps involve determining the basic approach for in-situ bioremediation at the site. Degradation of hydrocarbons can be accomplished either by stimulating microorganisms which presently exist in the subsurface, or by inoculating the ground with a specially cultured organism. A study completed at this site indicated that organisms capable of degrading condensate did exists naturally within the subsurface. However, their natural activity levels are too low to have any major effect on the contaminant levels. These organisms could be either stimulated in-place or cultured at surface in a bio-reactor and reinjected into the aquifer. One of these two options is preferred over the introduction of a foreign species. However, the selection of method and selection of microorganism is beyond the scope of this report.

The other key design consideration is the choice of oxygen delivery systems. The two main choices are air-sparging and injection of sources of molecular oxygen, such as hydrogen peroxide. Air-sparging is inexpensive, but results in maximum dissolved oxygen level of only about 10 mg/L. Hydrogen peroxide injection delivers much greater concentrations of molecular oxygen, but requires complex and expensive storage, handling and dosing equipment. Either or both delivery systems could be demonstrated as part of such a project.

Air Sparging Component

One advantage of the air-sparging system is that it could be coupled with SVE wells, and be used to simultaneously study the application of in-situ air-stripping or subsurface volatilization and vaporization system (SVVS), an innovative technology also recommended in the Phase IIA study. As air is bubbled through the contaminated aquifer, volatile organics are volatilized and carried towards the unsaturated zone. Once released as vapours in the unsaturated zone, they are removed by nearby vapour extraction wells. Such systems will undoubtedly have multiple benefits - removal of organics by volatilization, and stimulation of biological activity through oxygen enrichment.

The demonstration system should be designed to fully integrate the components described, and assess their performance singly and in combination. This could be accomplished by phasing in the various systems over time, or by conducting separate tests in different portions of the site.

A suggested conceptual design would involve installation of the SVE system described in demonstration opportunity #1, at a location near the flare stack and well RW-10. Operation of this system could proceed for one year, during which time the bioremediation laboratory and design studies could be completed. During the following year, the existing injection wells could be adapted for the chosen nutrient/bacteria injection program, and between 2 and 10 air-sparging wells completed over area between RW-10, RW-13 and the injection wells. Additional monitoring points would also be required. The system would have to be carefully instrumented and monitored to track remedial performance, and assess the need for modifications to oxygen or nutrient levels to keep the biological processes operating efficiently.

5.3 DEMONSTRATION OPPORTUNITY 3: TREATMENT OF DISSOLVED PROCESS CHEMICALS IN GROUNDWATER BY ADVANCED OXIDATION

5.3.1 Research Value

Plant B, as discussed above, has a pump-and-treat system installed and operating toluene and xylenes, is being recovered and treated by air-stripping. At present, air-stripping is being done conventionally, using a packed tower. Removal efficiencies to date have been above 95%. Volatilized hydrocarbons are presently being released to atmosphere.

The influent to the system has with time contained increasing concentrations of amines and amine degradation products, as signalled by TKN concentrations. Levels of TKN (nitrogenous compounds) are not reduced by the air-stripping process or by pre-treatment.

Air-stripping was the established technology recommended in the Phase IIA study for treatment of dissolved hydrocarbons in groundwater. Treatment of dissolved process chemicals in groundwater is a subject on which there is very little available information. The Phase IIA technology study has recommended the testing of advanced oxidation processes (AOP) as a potential solution. This site offers a good opportunity to demonstrate the practicability of such treatment to amine and amine degradation product contamination.

The obvious value of this demonstration opportunity is the chance to field test technologies which may be capable of dealing with the more difficult process chemicals found in groundwater around sour gas plants. The opportunity is made more attractive by the fact that the infrastructure needed to support and operate such a test is already in place. Such a demonstration would be of particular interest to the sour gas plant industry.

5.3.2 Design

The general approach to this program should be to make as much use as possible of existing facilities. As described above, the present treatment system is housed in a weatherproof building, and is capable of year-round operation. It is expected that an AOP unit could be housed within the existing structure.

Air-Stripper Enhancement with Heated Air

Waste heat from the gas plant could be piped down to the treatment building for use with the air-stripping system. Heat is available at the plant in the form of steam. A steam line could be run from the south part of the plant to the treatment building, a distance of about 500 m.

The steam could be used in several different ways to enhance volatilization of hydrocarbons from the influent. Steam could be passed through a heating jacket to warm the influent itself. Alternatively, the air countercurrent could be heated, or the stripper adapted to use a steam countercurrent. The final choice should be based on volatilization-efficiency calculations comparing predicted increases in volatilization with heat energy used, and the practicality and expense of setting up the required systems.

Off-gas treatment

The Phase IIA report recommended that for low concentration off-gases such as are discharged from air-strippers, activated carbon filters were preferred. Such a system could be readily installed within the existing building. Vapours could be collected from the top of the stripping tower, which protrudes from the top of the building by several feet, and ducted back into the building and to the carbon system. The choice of carbon system would depend on the research interests of the various funding groups.

The Phase IIA study also identified that advanced oxidation processes showed some promise in dealing with low-concentration off-gases. There are many different commercially available AOP systems on the market, using different oxidants and catalysts. The majority of systems presently available have been designed for water treatment. An AOP system could also be demonstrated for effectiveness in dealing with hydrocarbon of-gases at this site. The unit could likely be placed within the existing building, and vapours channelled down from the stripper outlet as described above.

6. DISCUSSION

One of the interesting features of the demonstration opportunities described is that they each encompass a variety of complementary technologies. For instance, opportunity # 2 describes the potential of studying remediation of condensate through pump-and-treat, combined with soil vapour extraction and eventually in-situ bioremediation. Enhancements to each process are suggested. In effect, this demonstration opportunity affords potential for field implementation and testing of no less than six established and innovative remedial technologies: pump-and-treat; soil vapour extraction and enhancements to SVE, off-gas treatment by catalytic oxidation or flaring, and in-situ bioremediation. This stresses a key finding of the Phase IIA report, that in most cases, a single remedial technology will not provide the entire solution to a problem. Adequate remediation of most problems at sour gas plants will require application of a number of complementary techniques, either in series, or phased-in progressively over time.

Each of the six demonstration opportunities presented offers different avenues for remedial technology application. A summary of the six opportunities and the technologies recommended is provided in Table 6.1. Opportunities exist for demonstration of technologies capable of dealing with the three major contaminant types at ASGP's: condensate liquids and associated hydrocarbons, process chemicals, and dissolved inorganics. Low pH problems are not represented. Of the six opportunities, five involve groundwater problems, and only one involves soil/unsaturated zone remediation. This imbalance reflects the scarcity of data on soil contamination available at ASGP's.

Further ranking or prioritization of the six opportunities was not considered useful. The opportunities presented are each valuable in their own way, and may be attractive to different groups or agencies. All are of considerable value to the Alberta sour gas processing industry. Many of the opportunities will fall readily within identified research priorities of major soil and groundwater research funding organizations, both in Canada and abroad.

In all cases it should be noted that some level of preliminary site characterization will be required, and that each remediation program must be treated as an individual site. All demonstrations should be conducted with close attention to the unique hydrogeological conditions of the particular site. In all cases, preliminary design studies and pilot-scale testing are highly recommended. To obtain the maximum possible research benefit from the proposed remediation demonstrations, it is recommended that particular emphasis be given to proper instrumentation of the systems to determine baseline conditions, assess remedial performance, and track efficiency. This is one area where remediation programs have traditionally been lacking (Mercer and Cohen, 1991).

TABLE 6.1
SUMMARY OF DEMONSTRATION OPPORTUNITIES

NUMBER	PLANT	CSC	SITUATION DESCRIPTION	TECHNOLOGIES REPRESENTED
1	B	S1A	condensate in unsaturated zone sands and gravels	soil vapour extraction enhanced SVE catalytic oxidation flaring off-gas bioventing
2	B	T1A	condensate in saturated zone sands and gravels	SVE pump-and-treat enhanced SVE off-gas treatment in-situ bio air sparging air-stripping
3	B	T1BC R1BC	treatment of process chemicals in groundwater	AOP system part of existing treatment train air-stripping pre-treatment

Accordingly, operation, maintenance and monitoring programs for the demonstration programs should be designed and accounted for in advance. In many cases, effectiveness of a remediation program will require several years to become apparent. It should be noted that such costs can typically reach several times initial capital costs over a multi-year program. Research programs of this type will typically incur higher operation and monitoring costs, as additional data are collected and more detailed analyses performed.

7. CONCLUSION

1. A detailed review of contamination situations available at five candidate sour gas plants has been performed, using information collected in previous phases of this project. Remedial technologies recommended in the Phase IIA study were matched to these contamination situations, and the combinations ranked based on the general level of subsurface characterization at the site, the research value to industry, problem significance, requirements for additional technology-specific site testing, the presence of remedial pre-requisites, and general technical and economic feasibility.

2. Three demonstration opportunities were chosen, encompassing a wide variety of the most common contamination situations at ASGP's, and involving several established and innovative treatment technologies.

3. Prioritization of the research opportunities is left to the various interested funding organizations, the CPA, and the plant operators themselves. Different opportunities will necessarily be of interest to different groups. All

of the opportunities presented hold value for the Alberta sour gas industry as a whole.

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REGIONAL HYDROCARBON CONTAMINATED SOIL RECYCLING FACILITY STANDARDS

Prepared for the
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ABSTRACT

In an effort to protect the environment from uncontrolled releases of petroleum products, the CPPI member companies have initiated environmental upgrading programs for their underground fuel storage systems in British Columbia. These programs have been restricted in recent years as a result of environmental regulations targeting contaminated soil. Contaminated soil is generated when steel underground storage tanks are upgraded to current standards.

The soil requiring treatment is typically sand backfill which contains a nominal volume of petroleum product. These soils can be treated in an engineered basin using bioremediation technology to reduce the level of contamination. Depending on the degree of treatment, the soil can be recycled as backfill or reused as landfill cover. In order to facilitate effective treatment of these soils, the CPPI member companies are promoting the development of regional soil recycling facilities.

20.2

REGIONAL HYDROCARBON CONTAMINATED SOIL RECYCLING FACILITY STANDARDS

INTRODUCTION

The Canadian Petroleum Products Institute (CPPI) is a nonprofit organization of petroleum refiners and marketers which represents the interests of the petroleum industry with regard to the environment, health and safety and business issues. The CPPI members in British Columbia include Chevron Canada Limited, Petro-Canada Products, Shell Canada Products Limited, Imperial Oil Limited, Products Division, Canadian Turbo Inc., and Husky Oil Operations Ltd.

In an effort to protect the environment from uncontrolled releases of petroleum products, the CPPI member companies have initiated environmental upgrade programs for their underground petroleum storage systems in British Columbia. The upgrade programs began in the early 1980s, and are expected to be completed within the next five years.

The British Columbia Ministry of Environment, Lands and Parks has proposed regulations which will require all underground storage tanks be upgraded to current technologies by 1998. The underground storage tanks in question are typically unprotected steel tanks which are 10 to 30 years old.

The current environmental regulations do not recognize the treatability of petroleum contaminated soil, making it increasingly difficult to proceed with scheduled environmental upgrades. To overcome the current regulatory obstacles, CPPI member companies are spearheading a program in BC to promote the treatment and recycling of these soils in a controlled manner.

Only about one-third of the total number of underground fuel storage tanks in British Columbia are owned by CPPI-member companies. The estimated number of underground storage tanks in British Columbia is as follows:

•	service stations	6 000
•	non service stations (municipal works yards, utility companies, fire halls, transportation companies, etc.)	12 000
		18 000*

* Residential furnace oil tanks are **NOT** included in the above estimate.

The creation of a sound soil recycling procedure will benefit all owners of underground storage tanks. CPPI members promote the development of several centralized soil recycling facilities within different regions of the province to treat locally generated soil.

BACKGROUND: THE NATURE OF THE PROBLEM

Underground storage tank technology was developed in the 1950s, as a result of the increase in domestic demand for gasoline. An important factor for service station layout was the fire safety hazard associated with the storage and handling of fuel. To protect the tanks and fuel lines from damage, most systems were installed below grade. The steel tanks installed in the early years did not have any corrosion protection, which limited their useful life. Operation of the service stations often resulted in small releases of fuel from accidental overfills, minor leaks, and careless handling practices. These releases entered the sand backfill around the tanks and flowed vertically to the water table, as shown on Figure 1.

Over a period of time, often years, some of the product released into the tank backfill may have migrated laterally into the surrounding native soil. The resulting impact ranges from low level residual soil contamination to, in some cases, free phase product and potential ground water contamination.

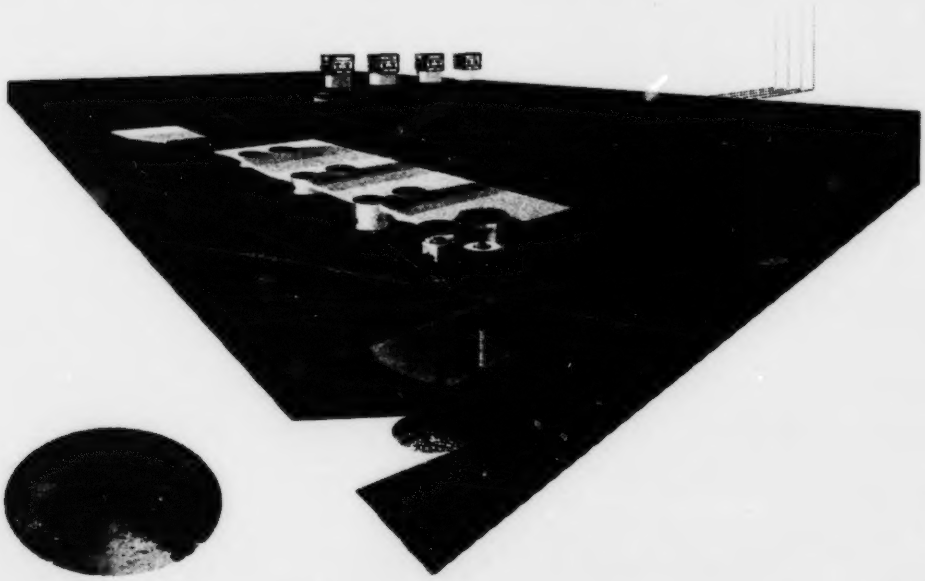


Figure 1 Typical steel underground storage facility with contaminated backfill and perched water table.

PREVENTION: UPGRADING WITH NEW TECHNOLOGY

New underground storage tank systems are being installed with improved technology to prevent future releases of petroleum products into the environment. As illustrated in Figure 2, many of these provisions meet or exceed the code of practice established by the Canadian Council of Resource and Environment Ministers, and have been adopted in principle by the BC Ministry of Environment Lands and Parks for the proposed underground storage tank regulations.

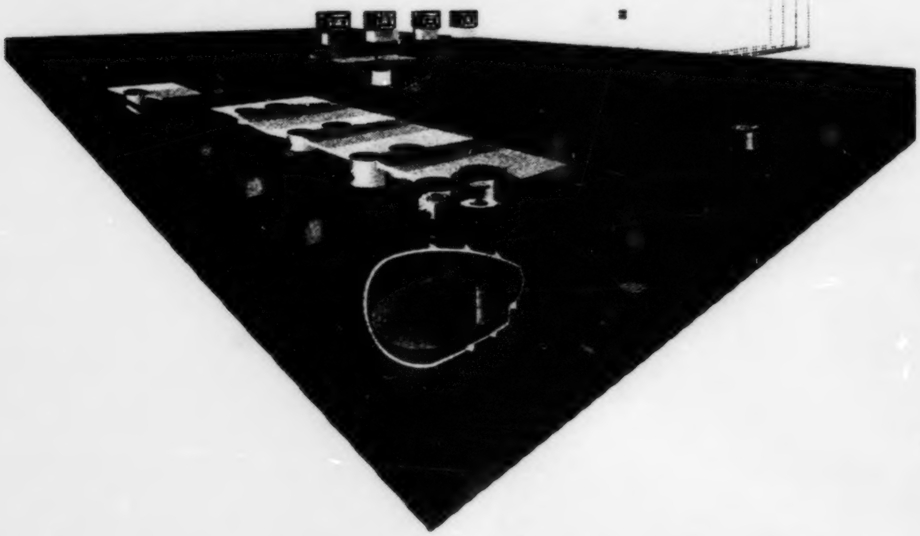


Figure 2 Typical double wall fibreglass storage tank installation with overfill protection, monitoring wells and pea gravel backfill.

THE UPGRADE PROCESS

When tank systems are upgraded, the sand fill must be excavated, as it is not suitable as backfill adjacent to new fibreglass tanks. Therefore, a service station upgrade can produce a substantial volume (250-350 m^3) of potentially contaminated soil which may require treatment prior to disposal off-site. Typically the soil is sampled and evaluated prior to excavation. Soil contamination which exceeds the special waste criteria currently must be managed on site, as there are no permitted treatment facilities in British Columbia. Lesser contaminated soils are often disposed as industrial waste in the absence of cost effective treatment options. Both of these options are undesirable; in the first instance this procedure disrupts the site, and the sites in question are often located in sensitive areas which are highly populated. Soil treatment operations on the service station sites are considered to be a nuisance and an eyesore by the public, as well as an impediment to effective treatment. Disposal of lesser contaminated soils in landfills places an unnecessary burden on the limited space available.

ENGINEERED SOIL TREATMENT SOLUTIONS

The purpose of developing soil recycling facilities is to receive, store, treat and finally recycle or reuse the treated soil in an environmentally acceptable way.

The establishment of regional soil recycling facilities will address the short term soil handling needs imposed by on-going tank replacement programs. Long term benefits will accrue from the ability to properly clean up sites without wasting valuable landfill space.

THE RECYCLING PROCESS

The process starts with an evaluation to determine the nature and extent of any contamination present on the site. Gasoline-contaminated soil will contain aromatic compounds [benzene, ethylbenzene, toluene, and xylenes (BETX)] at levels which may require remediation. Diesel-contaminated soil usually contains light aliphatic hydrocarbon (LAH) components at higher concentrations than the aromatic compounds. Depending on the contamination encountered, the key components are evaluated using soil analyses and the results compared to the provincial standards. Any soil above the appropriate standard (Level B or C, depending on land use) could be excavated and would be suitable for treatment at the recycling facility. End dump trucks are acceptable for transportation of the soil, as even high levels of contaminant are bound in the soil mass, and do not leach out over a short period of time.

Once delivered to the treatment site, the soil should be stored on an impermeable surface to prevent contaminant migration. A cover should be provided if rain is expected, but is not necessary to control volatile emissions, as these are nominal. Evaporation takes place only from the surface of the soil pile where there is direct exposure to the air. The bulk of the contamination is contained within the pile and does not readily diffuse through the outer soil layer.

THE TREATMENT BASIN

The proposed soil treatment facilities should be constructed with components which meet the design requirements of the special waste regulations. As illustrated in Figure 3, the components are designed to prevent discharges to the environment as follows.

- A hydrocarbon-resistant liner is used to contain soil and any leachate which is generated during the recycling process.
- A dyke or berm is constructed either using precast concrete or soil around the perimeter to contain the liner and ensure that the soil is contained while treatment takes place.

- A removable tarpaulin is used to cover the soil to minimize any influent from rain water.
- Monitoring piezometers are installed around the perimeter of the facility, both up and down-gradient to monitor in situ ground water conditions below the recycling facility.
- If using a vapour extraction system, off-gas collection and treatment may be installed to minimize any atmospheric discharges.
- Access to the site should be controlled with chain link fencing to prevent unauthorized entry.

A typical layout for a soil recycling facility is shown below in Figure 3.

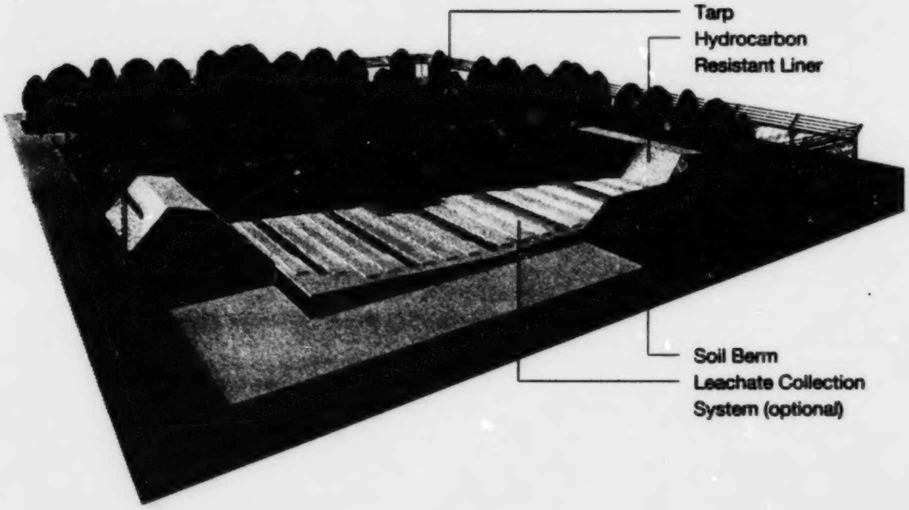
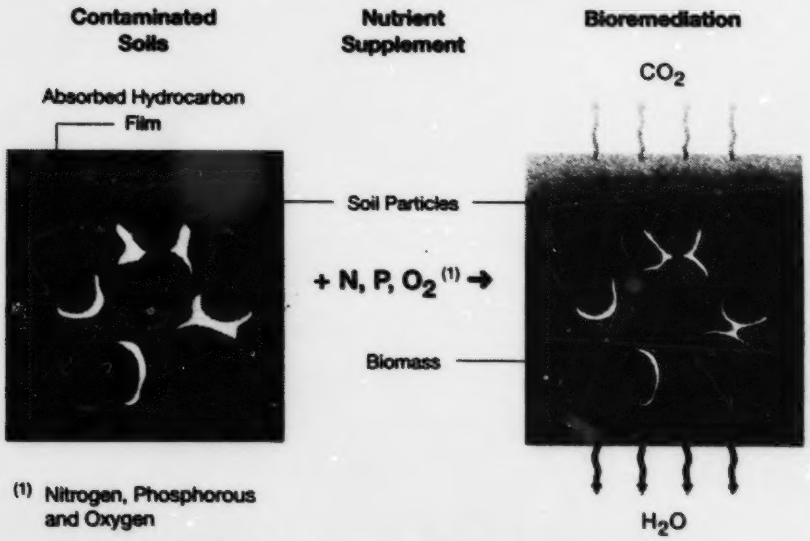

Tarp
Hydrocarbon Resistant Liner
Soil Berm
Leachate Collection System (optional)

Figure 3 Soil recycling basin

THE SOIL TREATMENT PROCESS

Mean hydrocarbon contamination levels are confirmed at the treatment site, and the soils are segregated according to classification. Any soils which have contamination greater than Level C are placed in the constructed basin for processing. Soils with contamination below Level C can be reused as appropriate. The soil treated at the recycling facility will have a hydrocarbon concentration which exceeds the Level C criteria, and even soil exceeding the special waste criteria can be effectively treated if approval is obtained.

Bioremediation is a process which uses naturally occurring microorganisms to degrade refined hydrocarbons in soil. Natural bioremediation can be enhanced with nutrients, water and oxygen to optimize the process. Laboratory analyses are used to determine the correct nutrient dosage for the soils being treated to maximize the rate of hydrocarbon degradation. The microorganisms use the residual hydrocarbon on the soil particles as food for growth, degrading the hydrocarbon to form carbon dioxide and water, as shown in Figure 4.



(1) Nitrogen, Phosphorous and Oxygen

Figure 4 Bioremediation of hydrocarbon on soil particles

Biological degradation is most often limited by the amount of oxygen available in the soil. Oxygen can be introduced to the soil by mechanical aeration or by air-injection. The soil is homogenized by mixing to encourage air flow through the soil, essentially increasing the volume of voids where oxygen can be trapped. Normally the soil is mixed on a weekly basis, and necessary nutrients are added selectively. The soil piles are covered to prevent infiltration of rain water between mixing intervals.

BENEFITS OF SOIL TREATMENT

The benefits of developing soil recycling facilities for hydrocarbon contaminated soils are as follows;

- reduces the potential for exposure to hydrocarbon contaminated soil at the urban service station sites;
- provides an increase in developable land within the community when clean sites are available for redevelopment;
- creates reusable industrial fill which can be used for a variety of purposes.

Impacts related to increased truck traffic in the immediate vicinity of the soil treatment facilities will be limited. The transportation phase of the work will not be conducted on a continuous basis because of the residence time associated with soil treatment and the seasonal nature of the proposed operating schedules.

The Canadian Petroleum Products Institute (CPPI) believes that soil treatment and recycling is an environmentally responsible approach to handling soil containing refined hydrocarbons. The CPPI member companies support this approach and promote the development of regional soil recycling facilities.

21.0

US EPA'S TECHNOLOGY SUPPORT PROGRAM FOR COOPERATION BETWEEN RESEARCHERS AND REMEDIATION DECISION-MAKERS

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ABSTRACT

The U.S. Environmental Protection Agency (EPA) Technology Support Project (TSP) provides funding to selected Office of Research and Development (ORD) laboratories to serve as a source of up-to-date technical information and associated expertise for EPA Regional decision-makers to help resolve technical problems regarding remediation at hazardous waste sites. Five ORD laboratories currently receive funding to operate Technology Support Centers (TSCs). Since inception of the TSP in 1987, TSCs have responded to over 1200 requests for technical assistance in support of remedial activities at hazardous waste sites. The mission of the Center at the Robert S. Kerr Environmental Research Laboratory (RSKERL) in Ada, OK, is to make available to site remediation decision-makers state-of-the-science information on fate, transport and treatability of contaminants in soil and ground water, along with scientific expertise needed to determine how it may influence remediation selection and performance. The RSKERL TSC responds to technical information requests with distribution of approximately 500 documents per month and, since its inception, has completed more than 16 technology transfer documents with another 9 currently in preparation; and has provided site-specific technical support at more than 230 different hazardous waste sites.

21.1

US EPA'S TECHNOLOGY SUPPORT PROGRAM
FOR
COOPERATION BETWEEN RESEARCHERS AND REMEDIATION DECISION-MAKERS

INTRODUCTION

The Superfund Technical Support Project (TSP) was established to provide direct, state-of-the-science and engineering technical support to Regional Remedial Project Managers (RPM) and On-Scene Coordinators (OSC). The TSP grew out of a concern for improving technical assistance to and consistency among Regional Superfund Programs. This project is a joint effort of the Regions, the Office of Research and Development (ORD), and the Office of Solid Waste and Emergency Response (OSWER). The TSP is funded and managed by OSWER's Technology Innovation Office. Specific objectives of the TSP are to:

- Provide technical support and assistance to Regional staff;
- Improve communications among Regions and ORD laboratories;
- Ensure coordination and consistency in the application of remedial technologies; and
- Furnish remediation technology workshops and state-of-the-science information for RPMs and OSCs.

TSP COMPONENTS

Major components of the program are the Regional Ground Water and Engineering Forums, the OSWER Environmental Response Team, and the Technology Support Centers (TSCs) located in designated ORD laboratories.

Ground Water and Engineering Forums

Regional Ground Water and Engineering Forums are comprised of one or more technical specialists, RPMs, or OSCs from each of EPA's ten regions. Forum members provide information to OSC/RPMs in their Regions regarding TSP efforts, research undertaken by the Centers, and problems and successes experienced by other Regions, including the application of specific remedial technologies at Superfund sites. Forum members:

- Channel communications among the Regions, TSCs, headquarters personnel, and existing EPA technical programs;

- Identify specific techncial issues and needs, and work with the Centers to address these issues in order to facilitate successful completion of site remediation;
- Act as a technical resource to the Regions and the Centers; and
- Route technical assistance information to Regional colleagues.

Environmental Response Team (ERT/NJ)

The ERT responds to releases of hazardous waste, chemical, oil, and also provides technical support in the areas of risk assessment, multi-media sampling and analysis, health and safety, cleanup techniques, and training for response personnel. Specific services include:

- Response techniques for emergency hazardous chemical releases
- Treatment technologies, sampling plans, and contaminant assessment
- Technical review for remedial and removal technology, safety, and preparedness
- Hazardous Materials Incident Response Training Program
- Site-safety plans, personnel protection, and safety

TECHNOLOGY SUPPORT CENTERS

Technology Support Centers provide site specific technical assistance in response to formal written Regional requests regarding site remediation-related issues, as well as routinely responding to hundreds of telephone inquiries. The types of technical assistance provided by the TSCs include a diverse range of both scientific and engineering support - from development of models and interpretation of data; to review of contractor work plans and reports; to development and evaluation of treatability studies and remedial alternatives. The Centers also develop technical Issue Papers and conduct technical workshops on critical topics identified by the Forums. Since the TSP was initiated in late 1987, the Centers have responded to over 1200 Regional requests for technical support at Superfund sites. The five ORD Technology Support Centers and the primary functional areas of each are:

Environmental Monitoring Systems Laboratory (EMSL/Las Vegas)

The Center of Monitoring and Site Characterization provides scientific and technical assistance in contaminant detection, hydrologic monitoring, site characterization, sample analysis, data interpretation, and geophysics. Specific areas of support include:

- Saturated and unsaturated zone monitoring
- Remote sensing, mapping, and geostatistics
- Analytical methods and quality assurance
- X-ray fluorescence field survey methods
- Mixed waste and radiological analysis

Risk Reduction Engineering Laboratory (RREL/Cincinnati)

The Center for Engineering and Treatment plans and conducts engineering, research and development related to treatment of solid and hazardous wastes, and provides technical support services involving specific treatment technologies and Superfund response processes including:

- Analysis of treatment alternatives
- Treatability studies
- Remedial design review
- Construction QA/QC methods
- Contaminant source control and geotechnical test methods

Environmental Research Laboratory (ERL/Athens)

The Center for Exposure and Ecorisk Assessment emphasizes support in the area of multimedia exposure and risk assessment modeling as related to selection of remedial action alternatives. An electronic bulletin board has been established to disseminate models and databases and to exchange modeling information. Technical support services involve:

- Models, databases, and analytical techniques
- Multimedia modeling of organic chemical and heavy metal pollutant fate
- Soil/water and surface water/sediment systems
- Ecological impact and ecorisk assessments

Environmental Criteria and Assessment Office (ECAO/Cincinnati)

The Center for Health and Risk Assessment provides rapid turnaround support in the assessment of Superfund health and risk issues. Specifically the Center:

- Provides chemical-specific health information

- Answers questions on the *Risk Assessment Guidance for Superfund (RAGS) Human Health Evaluation Manual*
- Develops interim and default approaches for issues related to risk assessment for Superfund sites and reviews site-specific Superfund risk assessments
- Develops, in cooperation with Superfund staff, site-specific and health-based trigger or cleanup levels for a contaminant
- Assists Regions in the identification of surrogate cleanup levels based on risk to human health

Robert S. Kerr Environmental Research Laboratory (RKSERL/Ada)

RSKERL is EPA's center for fate and transport research, focusing its efforts on transport and fate of contaminants in the vadose and saturated zones of the subsurface, methodologies relevant to protection and restoration of ground-water quality, and evaluation of subsurface processes for the treatment of hazardous waste. The Laboratory's Center for Subsurface Fate and Transport provides technical support pertaining to:

- Pump-and-treat technology for aquifer remediation
- In-situ biorestoration of soils and ground water
- Subsurface geochemistry
- Contaminant transport modeling
- Subsurface contaminant transformation

A quarterly breakdown of the total number of technical assistance requests submitted to the TSCs for each quarter since reporting was established is provided in Figure 1. This figure includes all Technical Support Centers and all Regions. A breakdown of new requests submitted to individual Centers over the past four quarters is provided in Figure 2. The graph in Figure 3 presents the distribution of technical support requests by Region during FY88, FY89, FY90 and the first three quarters of FY91.

RSKERL-ADA TECHNOLOGY SUPPORT CENTER ACTIVITIES

Background

Offering technical assistance to a variety of users on a variety of environmental issues has been a tradition at the RSKERL since its beginning in 1966. During ensuing years, the Laboratory gained a National and International reputation for its research related to: transport and transformation of contaminants in the subsurface environment; use of natural soil systems in treating waste; characterizing the hydrogeologic, abiotic, and biotic processes controlling contaminant transport and fate; and expression of these processes in mathematical models. A Laboratory reorganization in 1984 established the Applications and Assistance Branch which was specifically designated to focus on technology transfer and technical assistance activities. However, it was not until 1987 that events occurred which lead to a formalized structure wherein technical assistance became an integral part of the Laboratory's activities, particularly with regard to remediation of soil and ground water at hazardous waste sites.

Laboratory Organizational Structure

The RSKERL functional activities are focused within two major divisions (Figure 4). The "Processes and Systems Research Division" houses the Laboratory's in-house research complement, and the "Activities and Assistance Division" serves as the focus for extramural research, technology applications, and technical assistance. It is important to note that scientific and support expertise in each Division moves freely between discrete portions of the Laboratory's organizational entities to carry out its total technical mission. RSKERL research is guided, in large measure, by the Agency's pressing technical needs, and this operational mode assures that technology support is of the highest scientific caliber. It is the Laboratory's in-house research program and its extension through extramural research that is the foundation for the TSC.

TSC Organizational Structure

The Laboratory's TSC is part of the Applications and Assistance Branch. The Center is composed of a Core Team of RSKERL scientists (Figure 5) who are complemented by scientists from the Laboratory's Research Division; the National Center for Ground Water Research; the Center for Subsurface Modeling Support (CSMoS); and an on-site technical support contractor (Figure 6). Primary functions of each of the major RSKERL TSC components are:

RSKERL Research Program

Expertise in subsurface processes and systems from more than fifty in-house scientists and thirty-five universities and research institutions provides the scientific basis for the Technology Support Program.

RSKERL-Ada Technology Support Core Team (TST)

RSKERL scientists and engineers in the Applications and Assistance Branch provide a readily available source of interdisciplinary support to Regional RPMs and OSCs, with the technical support of an on-site contractor and associated consultants and subcontractors.

On-Site Contractor

Fourteen on-site contractor (Dynamac Corporation) support personnel, along with over 100 consultants and 6 subcontractors (including GeoTrans Inc.), provides support to the Core Team, carries out information transfer support activities, including providing operational support to the Laboratory's Subsurface Remediation Information Center (SRIC), provides operational support to CSMoS, and is developing a Subsurface Remediation (SRT) Technology Database in cooperation with Core Team staff.

RSKERL Center for Subsurface Modeling Support (CSMoS)

This Modeling Center is designed to provide modeling support related to the research, technology transfer, and technical assistance activities of the Laboratory pertaining to fate and transport of contaminants in the vadose and saturated zones of the subsurface environment. Adjunct to CSMoS is the International Ground Water Modeling Center (IGWMC).

National Center for Ground Water Research (NCGWR)

The NCGWR, a consortium of Oklahoma, Oklahoma State, and Rice Universities, develops and conducts long-range exploratory research to anticipate and address ground-water protection and restoration activites.

INFORMATION TRANSFER

The Robert S. Kerr Environmental Research Laboratory has always been involved with information transfer in an informal way. These activities became a structured part of the Laboratory in 1984. Information transfer activities often are carried out without specific requests but also may be in response to specific information requests or generic needs suggested by groups such as the Ground Water Forum or Headquarters Offices. The RSKERL Technology Support Center focuses on these activities through:

- Development and distribution of media specific databases and models, topic-specific information packets, Issue Papers and Briefing Documents; and,
- Development and conduct of workshops, seminars, conferences and short courses.

Information Transfer Components

Subsurface Remediation Information Center (SRIC)

The SRIC provides a forum for the rapidly developing, highly specialized information in this scientific arena. Activities are conducted involving developing, collecting, evaluating, coordinating, and disseminating information relating to transport and fate of contaminants in soil and ground water. In addition, the Subsurface Remediation Technology (SRT) Database provides site specific information concerning contaminants and remediation activities at existing hazardous waste sites. The purpose of the Database is to provide a single comprehensive source of information which can be shared and compared to other sites having similar problems or scenarios. The target audience includes: EPA Scientists, RPMs, OSCs, other key federal and state personnel associated with subsurface contamination and remediation activities, and site remediation contractors. The SRT Database is scheduled to be on-line by June of 1992.

Center for Subsurface Modeling Support (CSMoS)

This Modeling Center provides ground water modeling software and technical support services to public agencies and private companies throughout the nation. The primary aim of CSMoS is to manage and support the ground water models and databases resulting from research at the RSKERL. CSMoS integrates numerous individuals and organizations with expertise in all aspects of the environmental field in its effort to apply models to better understand and resolve ground water problems. Internally, CSMoS is supported by RSKERL scientists and engineers whose specialties include hydrology, chemistry, soil science, biology, mathematics, and chemical engineering. Externally, CSMoS is supported by the International Ground Water Modeling Center

(IGWMC), the National Center for Ground Water Research (NCGWR), GeoTrans, Inc., and a number of ground water modeling consultants from academia and the private consulting community. CSMoS provides modeling services in the following areas:

- Conceptualization
- Model Development
- Model Verification
- Model Validation
- Model Application
- Model Distribution
- Modeling Education

Models and/or databases available for distribution are:

- BIOPLUME II
- CHEMFLO
- GEOPACK
- OASIS
- RITZ
- SRT (available for staff search only)
- STF

Issue Papers and Briefing Documents

The concept of Issue Paper development was initiated in the early stages of the RSKERL TSC as a means of addressing a number of technical issues identified by the subsurface remediation community in general and the Ground Water Forum in particular as critical to subsurface remediation decisions required of the Regions. These are intended to be brief, state-of-the-science documents focused on a technical issue of expressed interest and prepared in a concise and readable format. Briefing Documents are much like Issue Papers in that they are prepared to address areas of special interest; however, they are most often of greater length and present the subject in greater depth. During its tenure of operation, the TSC has completed 16 of these documents and is currently working on 9 others. These documents have been widely distributed to the remedial-action user community. Selected examples for popular TSC documents include:

"Contaminant Transport in Fractured Media: Models for Decision Makers" (EPA/540/4-89/004)

Site characterization of fractured rock sites, and modeling ground-water flow and contaminant transport in fractured media, have been identified as major issues of concern of decision-makers at many Superfund sites. The ability to reliably predict the rate and direction of ground-water flow and contaminant transport in fractured rock systems would be of great value in planning and implementing the remediation of contaminated aquifers. This paper summarizes the current status of modeling ground-water flow and contaminant transport in fractured rock systems.

"Basics of Pump-and-Treat Ground-Water Remediations" (EPA/600/8-90/003)

A common means to contain and/or remediate contaminated ground water is extracting the water and treating it at the surface, commonly referred to as pump-and-treat technology. This report provides basic guidance on how to use available hydrogeological and chemical data to determine when, where, and how pump-and-treat technology can be used successfully to contain and/or remediate contaminant plumes. Ways to estimate the time required to achieve a specific ground-water cleanup goal also are discussed. Finally, the report addresses practical limitations of pump-and-treat technology given certain combinations of hydrogeolocial conditions and geochemical properties.

"Dense Nonaqueous Phase Liquids" (EPA/540/4-91/002)

Dense nonaqueous phase liquids (DNAPLs) are present at numerous hazardous waste sites and are suspected to exist at many more. Due to the numerous variables influencing DNAPL transport and fate in the subsurface, DNAPLs are largely undetected and yet are likely to be a significant limiting factor in site remediation. This Issue Paper focuses on current DNAPL literature and provides an overview from a conceptual fate and transport stand point of DNAPL phase distribution, monitoring, site characterization, remediation, and modeling.

"Bioremediation of Contaminated Surface Soils" (EPA/600/9-89/073)

Biological remediation of soils contaminated with organic chemicals is an alternative treatment technology that can often meet the goal of achieving a permanent clean-up remedy at hazardous waste sites. Generally, bioremediation involves use of naturally occurring microorganisms to degrade and/or detoxify hazardous constituents in the soil at a contaminated site to protect public health and the environment. Use of bioremediation techniques in conjunction with chemical and physical treatment processes is an effective means for comprehensive site-specific remediation, and is discussed in this report.

"Ground Water Sampling for Metal Analyses" (EPA/540/4-89/001)

Inconsistency in EPA Superfund cleanup practices occurs where one EPA Region implements a remedial action based on unfiltered ground-water samples, while another Region may consider a similar site to be clean based on filtered ground-water samples. RSKERL-Ada and EMSL-Las Vegas formed a technical committee of experts in the areas of ground-water geochemistry, inorganic chemistry, colloidal transport and ground-water sampling technology to examine this issue and provide technical guidance based on current scientific information. This report dicusses the findings and recommendations of the committee.

Workshops/Seminars/Conferences

These technology transfer vehicles are used to transfer state-of-the-science information pertaining to specific subsurface remediation-related topics, i.e., bioremediation, soil vacuum extraction, site characterization, DNAPLs, etc. to large audiences. Generally, RSKERL scientists supported by consultant expertise conduct such activities at Regional office locations or at the RSKERL-Ada. Since its inception in 1987, the TSC has conducted in excess of 60 workshops, seminars, or conferences in all ten regions.

Site Specific Activities

Specificially, the function of the TSC is to make available to site remediation decision-makers state-of-the-science information on transport and fate of contaminants in soils and ground water along with scientific expertise needed to determine how it may influence remediation selection and performance.

The type and duration of site-specific techncial support varies greatly among the different sites. Often, the request is for review of a contractor report or workplan for treatability studies or full-scale remediation involving technologies such as pump-and-treat, soil venting, or bioremediation (Figure 7). In many cases, involvement is much more more extensive. The RSKERL has been providing intermittent technical support at some Superfund sites for more than four years. Such support sometimes has involved extensive field investigations to better define site characteristics, treatability studies to determine technology applicability, and/or extensive modeling efforts to evaluate performance of existing remediation efforts.

Selected examples of Superfund sites with a chronological list of actions are:

North Cavalcade Superfund Site, Houston, TX

This site is an abandoned wood treating facility that operated for approximately 50 years. Major soil and ground-water contaminants include those associated with creosote treating operations, particularly the PAHs. The Regional RPM requested RSKERL to provide technical assistance during the remediation selection and implementation process.

July 1988 - Review comments for the site initial remedial design plan were provided to the RPM. In general, reviewers found that the scope of the remedial design covered the needs; but a lack of understanding of the biodegradation process was indicated.

June 1989 - A review of the field sampling and analysis plan was completed which suggested that substantial revision was needed in the areas of: (1) soil bioremediation treatability studies; (2) soil sampling; (3) free phase product isolation and recovery; (4) pump tests; (5) ground-water treatability studies; and (6) potential presence of dioxins and furans at the site.

January-March 1990 - Three versions of the Field Study Work Plan and the Field Sampling and Analysis Plan were reviewed. In addition, there were two trips to meet with the Region, State, and State contractor to discuss in-situ bioremediation, a site hydrogeological investigation, and location and removal of DNAPL's.

May 1990 - Previous investigations at the site resulted in conflicting hydrogeological information. Region VI requested RSKERL to assist in further studies to collect data to be used in remediation planning. TSC staff completed the work by logging eight wells and carrying out an aquifer test.

June 1990 - A meeting was held to discuss results from the field study and their implications on remediation planning. It was determined that the low permeability found at the site precluded the use of in-situ bioremediation. Bench and pilot studies were planned to determine the merits of using soil slurry reactors and/or land treatment.

December 1990 - Three members of the TSC completed a review of "A Treatability Study of Biotreatment and Soil Washing of Soil from the North Cavalcade Street Superfund Site, Houston, Texas." In general, findings were that conclusions and recommendations made in the report are not strongly supported by the data presented.

October 1990 - RSKERL provided comments on a document entitled "Remedial Design, North Cavalcade Superfund Site, Houston, TX, Work Plan for Groundwater Operation Unit." The response discussed the differentiation between the soil and ground-water operable units, the location of DNAPLs, and the location of monitoring wells.

May 1991 - RSKERL provided review comments to the RPM concerning two remedial design documents for the Ground-Water Operable Unit. The comments pointed out a number of problems in several areas. Among these were the selection of mud-rotary as the drilling technique of choice, the proper consideration of DNAPLs in estimating the time necessary for remediation, as well as a number of hydrogeological errors.

October 1991 - RSKERL provided review comments on documents entitled "Prefinal Remedial Design (90% Submittal), Groundwater Remediation/Source Removal, North Cavalcade Superfund Site, Harris County, Texas." In general, RSKERL stated that most of its earlier concerns were addressed in the documents; however, the strategy did not adequately deal with the questions of DNAPLs.

October 1990 - The TSC provided comments on a revised document entitled "Remedial Design, North Cavalcade Superfund Site, Houston, TX, Work Plan For Groundwater Operable Unit." The response suggested that biological treatment of the soil and aquifer material appears to be the most effective alternative presented for reducing PAH concentrations at the site.

December 1990 - Three members of the TSC completed a review of "A Treatability Study of Biotreatment and Soil Washing of Soil from the North Cavalcade Street Superfund Site, Houston, Texas." In general, the findings were that conclusions and recommendations made in the report are not strongly supported by the data presented.

January 1991 - Two members of the RSKERL TSC met in Dallas with the RPM, State personnel and State support contractor, to discuss a preliminary remedial design report for the site and various aspects of the preliminary remedial design report for the ground-water operable unit were also discussed.

April 1991 - Several members of the RSKERL TSC reviewed six proposals provided to the Region and from subcontractors bidding on the North Cavalcade Pilot Field Study. Of the six proposals, two were accepted with modifications, three were rejected, and one was not complete enough for evaluation.

Koppers/Beazer Superfund Site, Florence, SC

This active wood treating site is located about 1.5 miles east of Florence, SC. The plant site encompasses 200 acres where various wood treatment processes using creosote, pentachlorophenol, cooper-chromated arsenicals, and fire retardants have been operated since 1946. Both soil and ground water are contaminated with these wood treating chemicals. Technical support for the Koppers site was initiated in November 1989 with a request for the TSC to assess data being collected at the site in terms of its significance in selecting appropriated remediation technology for contaminated soil and ground water.

December 1989 - A detailed review of the site investigation plan was submitted by RSKERL. Review comments covered geology and hydrogeology in addition to monitoring well construction, sampling methods, and appropriate sampling parameters.

March 1990 - The TSC staff conducted a site visit to discuss with representatives from the State of South Carolina, PRP and PRP contractor, and Region IV the potential applicability of bioremediation at the site and the need for and location of additional monitoring wells required for hydrogeology investigations.

June 1990 - The TSC staff met in Starkville, MS, with the PRP contractor and Dr. Gary McGinnis of MIssissippi State University to discuss the potential for initiating a soil and ground-water bioremediation demonstration at the site.

August 1990 - TSC staff met in Atlanta with Regional RCRA and Superfund project managers, State RCRA and Risk Assessment personnel, and PRP and PRP contract personnel to discuss site specific technical issues: The Region requested that RSKERL continue to provide assistance during subsequent remediation activities including oversite of all bioremediation studies.

August 1990 - RSKERL reviewed the Draft Interim RFI Report and provided comments indicating the document to be markedly improved over an earlier version, especially with respect to hydrology. Comments addressing other areas of concern were discussed in depth.

October 1990 - RSKERL provided comments on data obtained at the site for use in determining the hydrochemical facies and the degree of mixing within the "A", "B", and "C" hydrogeologic zones. The response stated that data provided were not suitable for making these determinations.

October 1990 - An additional response was provided concerning a review of ground-water data collected during a recent investigation at the site. The data were reviewed for use in determining the hydrochemical facies and degree of mixing of ground water within four hydrogeologic zones identified at this site.

November 1990 - RSKERL provided a review of the proposed aquifer test design which expressed concern over several aspects of the test design, the primary concern centering on the distance between the pumping well and the nearest observation wells.

December 1990 - A member of the TSC provided on-site technical assistance for an aquifer test at the site. The 72 hour test, conducted by facility consultants, was designed to acquire data concerning the hydraulic connection between semi-confined hydrogeologic units below depths of approximately 70 feet and the overlying units.

March 1991 - RSKERL provided review comments concerning an On-Site Bioremediation Studies Work Plan for the site. The comments suggested that considerable revision of the Work Plan would be required before final implementation, expecially as related to the in-situ operation.

July 1991 - RSKERL reviewed the sampling and analysis plan to be used for characaterization of excavated drip track soils at the site. In general, the review comments stated that the plan, without modification, would not provide sufficient information concerning distribution and variability of contaminants within the various soil piles. Concerns were expressed pertaining to the compositing of samples, number and location of soil cores, and analysis of volatile aromatic contaminants.

September 1991 - Three members of the TSC participated in a meeting in Atlanta to discuss the RCRA Facility Investigation being conducted at the site. Issues discussed included progress of the hydrogeologic investigations and proposed bioremediation studies.

November 1991 - A conference was held at RSKERL with representatives of Region IV, Beazer East, supporting consultants, and three members of the TSC staff to discuss bioremediation studies proposed for the site. The principal topic of discussion was the performance of an in-situ vadose zone bioremediation study, including its design, oxygen and nutrient delivery system, and performance monitoring.

SACO Tannery Superfund Site, Saco, ME

The SACO Tannery waste site is located on 233 acres and contains 53 waste pits and two lagoons which were used for disposal of chromium sludge, acid and caustic wastes, and methylene chloride. Major concerns at this site pertain to mobility of chromium and facilitated transport of arsenic due to the change of pH resulting from use of lime at the site. Technical support was initiated in February 1990 involving a definition of geochemical conditions which promote the mobility of metals including arsenic, chromium, and lead.

March 1990 - A response to the initial request provided a rather detailed explanation of the theory of metals transport as well as insights gained from a field scale research investigation of tannery sludges carried out by RSKERL scientists.

May 1990 - After a review of the Remedial Investigation Report, two members of the TSC met at the site with representatives of Region I and the Maine Department of Environmental Protection. Soil cores were collected and shipped to RSKERL for studies aimed at characterizing the mobility of chromium as well as the possible facilitated transport of arsenic. Wells that were to have shown elevated levels of arsenic were sampled by RSKERL personnel.

July-August 1990 - Three members of RSKERL conducted colloid transport studies to characterize site material. Tests were run to address questions essential to the Region in determining the type and extent of remediation needed at the site. Colloidal transport of metals in ground water is a major researach activity at RSKERL, and scientists were able to evaluate state-of-art ground-water sampling technology while at the same time providing assistance to the Region.

May 1991 - Three members of the TSC sampled 9 wells at the site. Five of the monitoring wells were completed in bedrock and four were completed in glacial till. The sampling objective was to determine the occurrence and form (speciation) of arsenic as speciation affects its mobility, toxicity, and possible organic complexation as well as colloidal transport. The arsenic forms of arsenite and arsenate were separated in the field by the use of ion-exchange columns. Samples were collected under nitrogen for electrochemical analysis at the laboratory. Colloids were collected on filters for scanning electron microscope analyses. A borescope was used to investigate ground-water flow, velocity, direction, and colloidal density.

May 1991 - An RSKERL scientist attended a meeting at the Region I office with Regional representatives and their Contractor to evaluate data collected to date and discuss future well locations, sampling protocols, and additional research.

Sylvester Superfund Site at Gilson Road, Nashua, NH

The Gilson Road site was the location of unpermitted disposal of household refuse, demolition debris, and hazardous materials in the 1960s and 1970s. An estimated 800,000 gallons of aqueous hazardous wastes were disposed of at the site between 1975 and 1979. Presently the shallow aquifer and underlying bedrock aquifer are contaminated with: tetrahydrofuran, toluene, benzene, chloroform, methylene chloride, phenols, trichlorotheylene, and other organic compounds. Effectiveness of the pump-and-treat remediation system is currently under evaluation.

June 1990 - A Regional request specifically addressed assistance in the adaptation and utilization of an existing simulation model for the site, including the Regions concerns for:

1. on going extraction of contaminated ground water within the containment area to be efficient and expenditous,
2. recharge of treated ground water to enhance the flushing of contamination from the containment area,
3. whatever residual contamination that exists outside the containment area does not pose a threat to public health and the environment and,
4. when ground-water treatment goals specified in the ROD for the containment area are attained (and pumping ceases) the transport of any remaining contamination does not pose a threat to the surrounding area.

June 1990 - RSKERL personnel met separately with Dr. Milovan Beljin, University of Cincinnati, and Richard Willey, Region I Hydrogeologist, to outline funding needs, determine respective responsibilities of those involved, and agree on specific outputs of the modeling effort. It was anticipated that Dr. Beljin and RSKERL personnel would coordinate modeling efforts to adapt and utilize an existing model for the site to address the Regional concerns and improve the efficiency of ongoing pump-and-treat remediation activities.

August 1990 - An RSKERL representative met with Regional personnel in Boston to discuss site modeling efforts. It was anticipated that results from ground-water flow and contaminant transport modeling would help increase efficiency of the existing ground-water remediation project.

November 1990 - A member of the TSC and Dr. Beljin visited the site and conducted field studies. Pressure transducers were installed in 9 wells with the assistance from Region I personnel. Data loggers recorded water level fluctuations/recharge system. Data collection continued for the next two months.

February 1991 - A member of the TSC visited the site to retrieve a data logger and pressure transducers which recorded water-level fluctuations within the containment area. These and other data were to be used to calibrate a flow model for the site. Proposed locations of additional wells at the site were discussed with Regional scientists.

April 1991 - Representatives of the TSC met with Region I personnel in Boston to discuss details of ongoing ground-water modeling efforts for the site. Results of recent modeling efforts were presented and suggestions made for future modeling. The modeling effort would be directed towards evaluating effectiveness of the existing pump-and-treat/recharge system and providing suggestions for improving efficacy of contaminant removal from the system.

August 1991 - A member of the TSC met with Dr. Beljin to finalize a technical assistance report to Region I entitled "Ground-Water Modeling of the Gilson Road Site, Nashua, New Hampshire." The report contained a technical review of previous ground-water modeling efforts at the site and presented a proposal for future modeling efforts.

SUMMARY

RSKERL and the other Support Centers have just completed their fourth year of activity. During this period RSKERL has responded to over 320 site specific requests for assistance. At the end of 1991, the RSKERL Technology Support Center had 68 active and 163 completed site specific projects encompassing an involvement at a total of 231 Superfund or RCRA locations. The areas of greatest activity, involved in about 45 percent of the technical assistance requests, were concerned with the planning or review of RI/FS and Remedial Design investigations. Nearly 40 percent of the RSKERL technical assistance was evenly divided between bioremediation, soil remediation, land treatment, and modeling. The remaining technical assistance was provided in a variety of areas including pump-and-treat, soil vacuum extraction, and metals.

A wide variety of specific research documents and topic-specific information packages pertaining to site investigation as well as transport, transformation and remediation of contaminants in the subsurface have been prepared and/are provided to the Regions, Headquarters, states, researchers, and others who are involved in this technical arena.

Software driving the Subsurface Remediation Technology Database is in place, and data are being entered into the system. Revision of software for the Soil Transport and Fate Database, including update of the Database entries has recently been completed; and copies of the revised Database have been transmitted to prototype recipients.

FINAL OBSERVATIONS

Remediation of hazardous waste sites, especially the subsurface component, is a relatively new, extremely complex, interdisciplinary science. Success is determined more by experience than by hardware. The Technical Support Project has been very successful in minimizing the time between development of the science and application of that scientific knowledge to decision making in the field. The Technical Support Project not only transfers knowledge from the research to the field but acts as a critical feedback mechanism for focusing research efforts on the highest priority and most productive areas.

DISCLAIMER

Although the research described in this article has been funded wholly or in part by the United States Environmental Protection Agency through Contract Number 68-C8-0058 to Dynamac Corporation, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

BIOGRAPHICAL INFORMATION

John E. Matthews, currently serves as Chief, Applications and Assistance Branch, Extramural Activities Division, Robert S. Kerr Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency. The Applications and Assistance Branch serves as a focal point for technical assistance and transfer of Laboratory research findings to the user community. He has a B.S. and M.S. degree from Utah State University, College of Natural Resources with emphasis in biological sciences. He has 24 years of service with EPA and predecessor agencies, 16 years of which has been with the Office of Research and Development. Primary areas of speciality include subsurface environmental investigations, land treatment, and other soil bioremediation technologies.

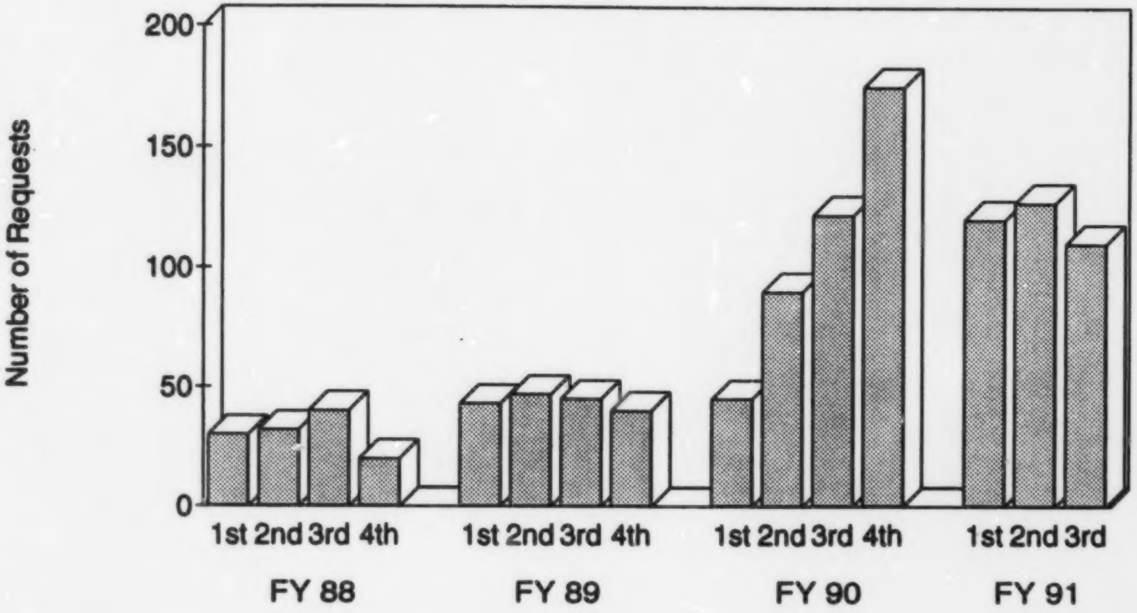

Figure 1. New Requests by Fiscal Quarter for All Regions and Centers

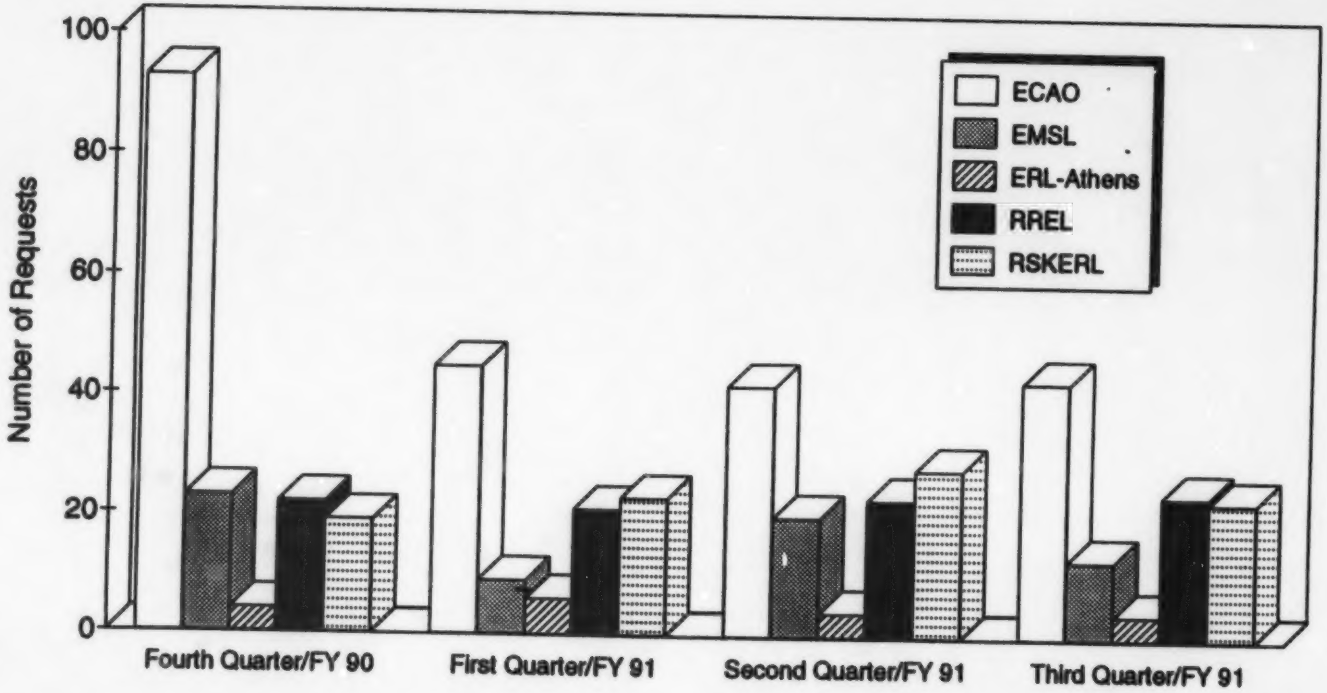

Figure 2. New Requests Submitted to TSCs During the Past Four Quarters

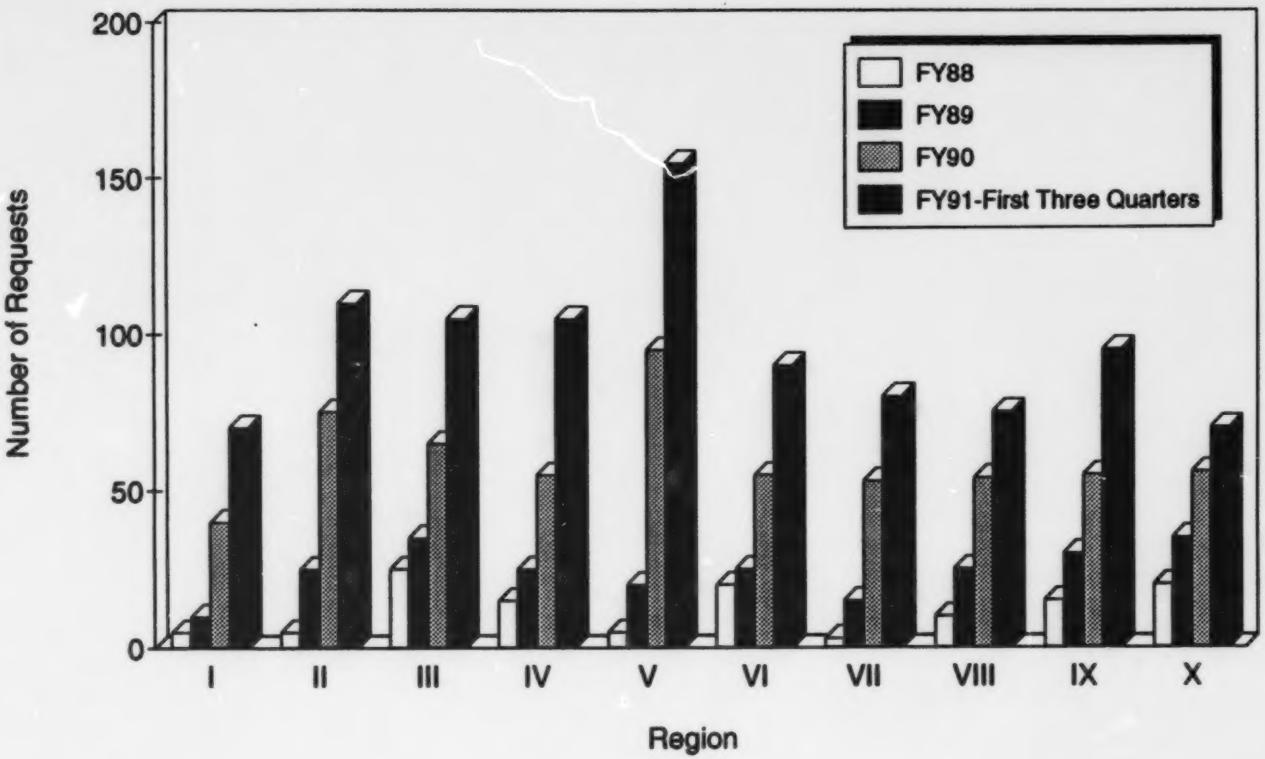

Figure 3. Site-Specific Technical Assistance Requests by Region

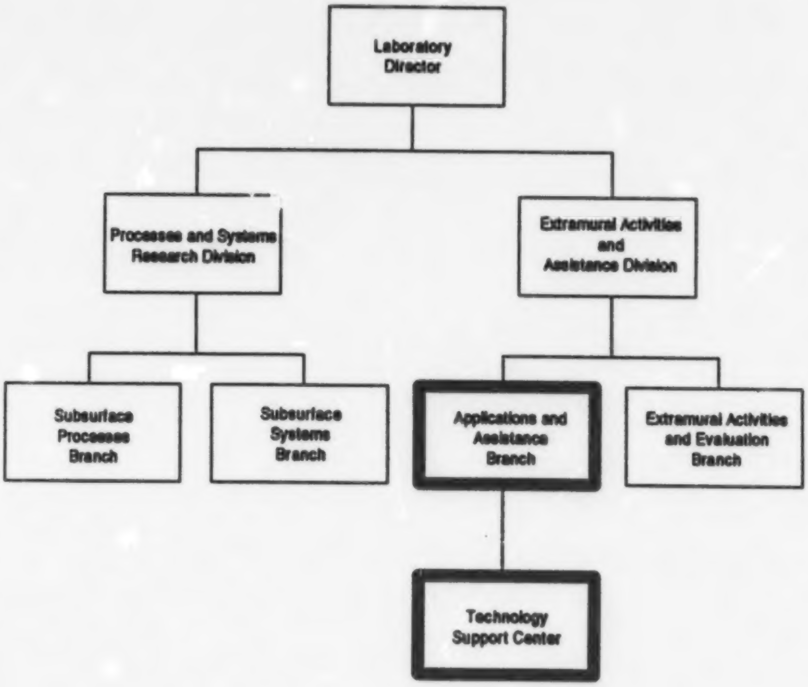
Laboratory Director
Processes and Systems Research Division
Extramural Activities and Assistance Division
Subsurface Processes Branch
Subsurface Systems Branch
Applications and Assistance Branch
Extramural Activities and Evaluation Branch
Technology Support Center

Figure 4. RSKERL Organization Chart

John Matthews	Branch Chief/Biologist
Don Draper	Director Technology Support Center/Hydrogeologist
Jerry Thornhill	Hydrogeologist
Steve Acree	Hydrogeologist
Bert Bledsoe	Chemist
David Burden	Hydrologist/Soil Scientist
Dom DiGiulio	Hydrologist/Engineer
Scott Huling	Environmental Engineer
Joe Williams	Soil Scientist
Randall Ross	Hydrogeologist
Hugh Russell	Microbiologist
Vacant	Environmental Scientist
Vacant	Environmental Scientist

Figure 5. RSKERL Technical Support Team

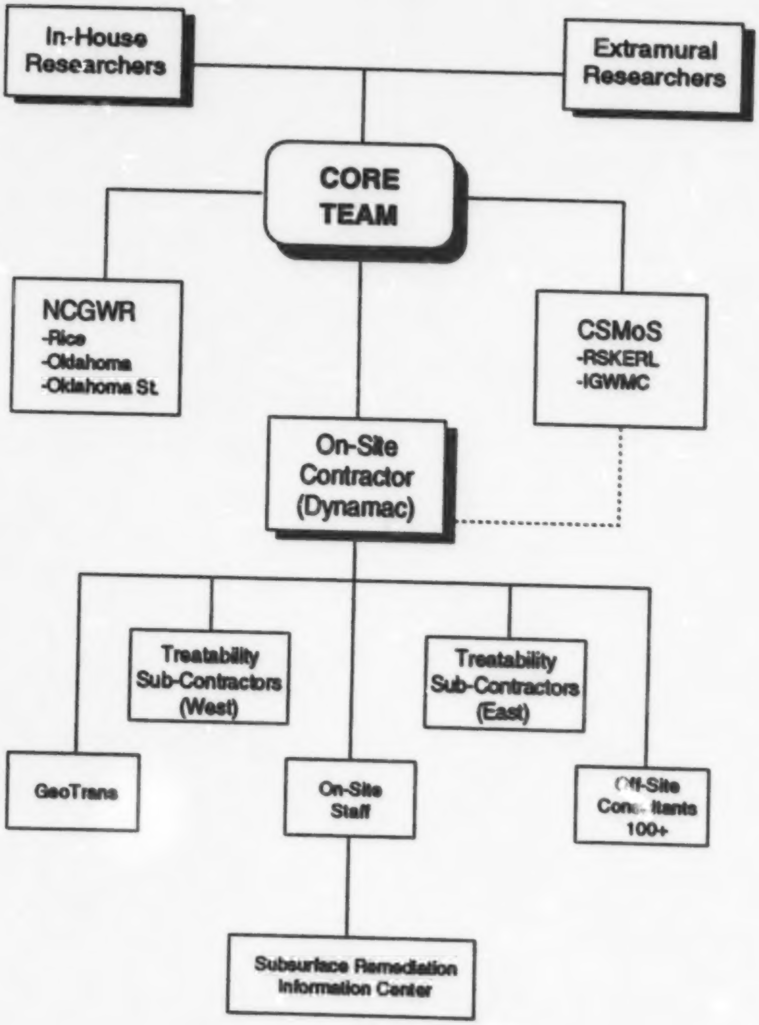
In-House Researchers
Extramural Researchers
CORE TEAM
NCGWR
-Rice
-Oklahoma
-Oklahoma St.
CSMoS
-RSKERL
-IGWMC
On-Site Contractor (Dynamac)
Treatability Sub-Contractors (West)
Treatability Sub-Contractors (East)
GeoTrans
On-Site Staff
Off-Site Consultants 100+
Subsurface Remediation Information Center

Figure 6. RSKERL Technology Support Center

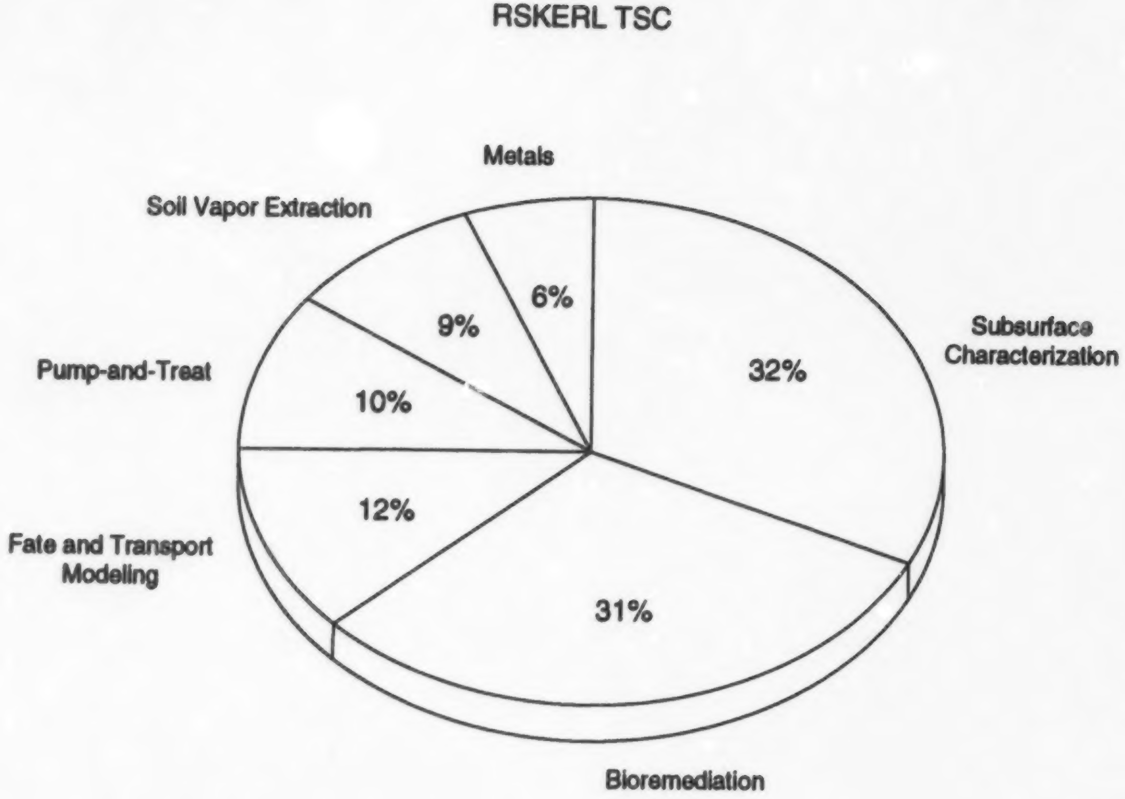

Figure 7. Principal Areas of Technical Assistance Request

22.0

DELEGATE LIST

2nd Annual Symposium on Groundwater & Soil Remediation Attendee List

Company	Name		Title	City
	Heather	Oiye	Student	Vancouver
	DJ	Alperovitz	Student	Nanaimo
	604 754-5801			
	Paula	Santos	Student	Vancouver
	604 435-2975			
	David	Hutchinson		Mission
	(604) 826-5332			
	Monty	Bruce	Student	Victoria
	604 380-9896			
Acres International Limited	Colin	Beresford	Project Manager	Calgary
	253-9161			
Alberta Environment	Walter	Cercici	Hydrogeologist	Edmonton
	427-6182 (422-6193			
Alberta Environmental Research Committee	Brian	Hammond	Chairman Grants Advisory	Calgary
	297-2360			
Alberta Research Council	Boleslaw	Ignasiak	Manager Coal Upgrading	Devon
	987-8125			
Alpine Environmental Ltd.	Edward	Lambert	President	Drayton Valley
	542-5780			
Alpine Environmental Ltd.	Roxanne	Kosiorek		Drayton Valley
	542-5780			
Alyeska Pipeline Service Co.	Ingrid	Gadpaille	Environmental Support	Anchorage
	907 265-8981			
Alyeska Pipeline Service Co.	Chuck	Livers	Project Engineer	Anchorage
	907-265-8134			
American Petroleum Institute	Bruce	Bauman	Senior Environmental	Washington
	202-682-8345			
Amoco Canada Petroleum Company Ltd.	George	Collin	Supervisor-Environmental	Calgary
	234-4357			

2nd Annual Symposium on Groundwater & Soil Remediation Attendee List

Company	Name		Title	City
Amoco Canada Petroleum Company Ltd.	John 234-4373	Ward		Calgary
Aqua-Flo Testing & Equipment Ltd.	Hugh 604 530-8118	Reed	Manager	Langley
Arthur D. Little, Inc.	James (617) 864-5770	Rice	Geologist	Cambridge
Ashwarren International Inc.	Michael (604) 684-5111	McDowell	President	Vancouver
ASL Analytical Service Labs	Allan 604 253-4188	Maynard	Senior Partner	Vancouver
ASL Analytical Services Labs	Howie 604 253-4188	Ho	Chemist	Vancouver
B.C. Environment	D. 604 565-6452	McQuillan	Env. Safety Officer	Prince George
B.C. Environment	Blake 604 565-6445	Medlar	Head Env. Safety Section	Prince George
B.C. Environment	Doug 604 398-4533	McIntosh	Municipal Section Head	Williams Lake
B.C. Environment	Rodger 604 398-4540	Hamilton	Env. Protection Officer	Williams Lake
B.C. Environment	Udo 604 387-3609	Wittneben	Soil Specialist	Victoria
B.C. Environment	Louise 604 584-8822	Ouellet	Head-Special Waste	Surrey
B.C. Environment	Alex 604 847-7259	Grant	Safety Officer	Smithers
B.C.Environment	Lloyd 604 356-1923	Johansson	Contaminated Sites	Victoria
B.C. Environment	R.P. (604) 549-5499	Colvey	Environment Saftey	Penticton

2nd Annual Symposium on Groundwater & Soil Remediation Attendee List

Company	Name		Title	City
B.C. Environment	D.K. (604) 493-8261	Boyes	Environment Safety	Penticton
B.C. Environment	Peter (604) 493-8261	Jarman	Industrial Section Head	Penticton
B.C. Environment	Ronald (416) 467-3042	Lall	Decommisioning Specialist	Toronto
B.C. Environment	Douglas 604 584-8822	Pope	Sr Environmental	Surrey
B.C. Environment	Debra 604 584-8822	Corns	Environmental Protection	Surrey
B.C. Environment	Ian 604-584-8822	MacDonald	Senior Environmental	Surrey
B.C. Environment	Barry 604 669-1114	Olsen	Project Manager-Pacific	Vancouver
B.C. Hydro	Peter (604) 663-4390	Roth		Vancouver
B.C. Hydro	Angie (604) 663-4390	Deaust		Vancouver
B.C. Min. of Environment Lands & Parks	Linda 604 565-6448	Elder	Environmental Protection	Prince George
B.C. Min. of Environment Lands & Parks	Robert 356-8383	McLenehan	Contaminated Sites Unit	Victoria
B.C. Min. of Environment Lands & Parks	John 356-8383	Wiens	Soil/Hydrogeology Spec.	Victoria
B.C. Min. of Evironment Lands & Parks	R.H. (Bob) 604 356-6027	Ferguson	Director Standards and	Victoria
B.C. Research	Hamdy 604 224-4331	El-Rayes	Senior Env. Eng.	Vancouver
B.C. Research	Matthew 604 224-4331	Crowe	Research Scientist	Vancouver

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Company	Name		Title	City
B.C. Water & Waste Assn.		Shepherd		
Barenco Inc.	Paul 416 258-3632	Rew	Environmental Engineer	Dundalk
Bell Pole	E. 604 547-2131	Garey	Environmental Coordinator	Lumby
Bennett Remediation	Lawrence 604 681-8863	Pertile	Vice President	Vancouver
Bennett Remediation	John 604 681-8863	Bennett	C.E.O.	Vancouver
Bio-Rem Canada Co.	Uwe 604 534-0166	Boecker	Pres.	Surrey
Bover Environmental Services Group	Paul 604 984-4450	Beauchemin	Manager	North Vancouver
Burlington Environmental Technology Office	Alex 416-336-6438	Lye	GASReP Coordinator	Burlington
C.A.R.E. International Ltd.	Ron 264-2273	McCready	Vice President R & D	Calgary
Canadian Turbo Inc.	Doug 294-6586	Normandin	Manager Environmental	Calgary
Cantest Ltd.	Don 604 734-7276	Noot	Supervisor	Vancouver
Celanese Canada Inc.	Andrew 471-0511	Day		Edmonton
Centreal Projects Group Inc.	William 416 470-6570	Penny		Markham
CET Environmental Services Corp.	Feramarz 251-7888	Bogzaran	Manager Technical	Calgary
CH2M Hill Engineering Ltd.	Lisa 519-579-3500	Mendonça	Project Engineer/Jr.	Waterloo

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Company	Name	Title	City
Chemac Environmental Services	Jock Hawkey (604) 763-1535	Manager	Kelowna
Chemtrack Canada Ltd.	Jerry Coxey 604 646-2154	President	Sooke
Chevron Canada Limited	Robert Stephenson (604) 668-5300	Engineering Superviser	Vancouver
City of Kelowna	Mark Watt 604 862-3341	Environmental	Kelowna
City of Port Coquitlam	Andrew Deboer 604-944-5411	Project Engineer	Port Coquitlam
Clean Earth of New Castle	Henri Molleron (302) 427-6633	Chairman of the Board	New Castle
Clifton Associates Ltd.	A. Wayne Clifton (306) 721-7611	Principal	Regina
Clifton Associates Ltd.	Carol Adams 306 721-7611	Project Hydrogeologist	Regina
Clifton Associates Ltd.	Leonard Lam 263-2556	Senior Project Engineer	Alberta
CN Rail	Brian Pimblett (403) 421-6497	Environmental Protection	Edmonton
Colt Engineering Corporation	Bob Becker 258-8000	Sr. Environmental	Calgary
Colt Engineering Corporation	Wayne Egan 258-8000	Manager Project	Calgary
Conestoga-Rovers & Assn.	Ron Frehner 519 725-3313	P. Eng.	Waterloo
Constable Associates Consulting Inc.	G.A. Constable (604) 688-1773	President	Vancouver
Corp. of Burnaby-Environmental Health	Dipak Dattani 604 294-7390	Supervisor-Public Health	Burnaby

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Company	Name		Title	City
Corp. of Burnaby-Environmental Health	Ken 604 294-7390	Solanki	Acting Chief Public Health	Burnaby
CPPI	Roger 613 232-3709	Lafleur	Environmental Coordinator	Ottawa
Crockite Res. Ltd.	Murray 604 986-5873	McClaren	President	North Vancouver
Dalhousie University	Ross 902 428-3464	McCurdy	Assoc. Professor	Halifax
Dearborn Environmental Consulting Group	Alan 416-279-2222	Seech	Research Scientist	Mississauga
Dearborn Environmental Consulting Group	Igor 416-279-2222	Marvan	Manager	Mississauga
Department of Chemical Engineering	Dwijen (403) 492-3720	Banerjee	Research Associate	Edmonton
Dept. Environment and Lands	Raymond (709) 576-5724	Matthews	Regional Environment	St. John's
Dept. of Civil Engineering	A. 204 474-6376	Sparling	Doctor	Winnipeg
Dept. of Environment & Public Safety	Diane (306) 787-5793	Livingston	Project Officer	Regina
Dept. of National Defense	Keith 604 858-1667	Armstrong	Environmental Officer	Chiliwack
Dept. of Soil Science	Kevin (403) 472-4143	Ball	Graduate Student	Edmonton
Dept. of Soil Science	Baoshan (403) 492-6482	Xing	Graduate Student	Edmonton
District of Coquitlam	Mike 604 526-3611	Iviney	Engineering Technologist	Coquitlam
Domtar Inc.	Brent 476-1385	Mitchell	Divisional Engineer	Edmonton

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Company	Name	Title	City
Domtar Inc.	Alain Liard 514-457-8272	Sr. Hydrogeologist	Senneville
Dow Chemical Canada Inc.	Ken Tsang 998-8440	Manager Environmental	Fort Sask.
DuPont Canada Inc.	Steve Lauridsen 613 348-4230	Assoc. Dev. Eng. Environ.	Maitland
DuPont Canada Inc.	Paul Foster 416 427-5304	Sr. Process Engineer	Ajax
Ecologic Systems Corp.	John Lewis (403) 266-4125	Marketing Associate	Calgary
Econotech Services Ltd.	T. Peel 604 526-4221	Manager-Analytical	New Westminster
Energy Resources Conservation Board	Darryl Haas 297-2625	Environmental Engineer	Calgary
Envirochem	Douglas Grimes 604 986-0233	Hydrogeologist	North Vancouver
Envirochem Services	Douglas Whiticar 604 986-0233	Sr. Environmental	North Vancouver
Environment Canada	Maria Dober 902-426-6144		Dartmouth
Environment Canada	Glen Allard 819 953-3090	Director Technology	Hull
Environment Canada	G. Hewko 819 953-0962	Manager DESRT Program	Hull
Environment Canada	Ned Lynch (819) 953-0459	Manager	Hull
Environment Canada	Rick Scroggins 819 997-1223	Industrial Programs	Ottawa
Environment Canada	Dieter Theiss 604 666-6948	Envir. Project Engineer	North Vancouver

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Company	Name		Title	City
Environment Canada	Richard	Glue		Burlington
Environment Canada Tech. Dev. Branch	Dave 819-953-5228	Hutchison	Dept. IRAP Program Mgr.	Hull
Environment Canada Tech. Dev. Branch	George 819-953-5228	Hill	Chief of Industrial	Hull
Environment Canada-Emergencies	Caroline 613 991-1840	Ladanowski	Project Engineer	Ottawa
Environmental Network Inc.	Peter 255-7444	Broadbent	Vice President Operations	Calgary
EPA	Robert 206 553-1512	Stamnes		Seattle
ERM-Canada Inc.	Hugh 604 684-4434	Harris	President	Vancouver
FecFlow Consultants Inc.	G. 709 753-5101	Bursey	Project Hydrogeologist	St. John's
Fletcher Challenge	W. 604 654-4082	Conolly	Project Engineer	Vancouver
Fraser River Harbour Commission	Patricia 604 524-6655	Weber	Environmental	New Westminster
Gartner Lee Limited	Robert (604) 299-1445	Nicholson	Civil Engineer	Burnaby
Gartner Lee Limited	Geoff 416-477-8400	Westerby	Principal	Markham
Golder Associates Ltd.	Brenda 604 879-2266	Boyle	Geological Engineer	Vancouver
Golder Associates Ltd.	Leo 416 567-4444	Lahti	Principal	Mississauga
Groundwater Solutions Ltd.	Kaush (403) 237-0606	Rakhit	Hydrogeologist	Calgary

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Company	Name		Title	City
Groundwater Solutions Ltd.	James	Freeman	Hydrologist	Calgary
	(403) 237-0606			
Groundwater Technology	Kendall	Fullerton	Business Developer	Mississauga
	416 670-1700			
Gulf Canada Resources Ltd.	Lin	Callow	Manager Reclamationn	Calgary
	233-3924			
Gulf Canada Resources Ltd.	Perry	Gerwing	Environmental Advisor	Calgary
	233-3192			
Gulf Canada Resources Ltd.	Bernd	Patterson	Environmental Advisor	Rky. Mt. House
	845-8167			
Hazco Engineering & Contracting Ltd.	John	Thompson	V.P. Engineering	Calgary
	297-0445			
HBT Agra Ltd.	L.	Ginnever	B.A.Sc.	Burnaby
	604 294-3811			
Husky Oil Ltd.	Kong	Ng	Senior Staff	Calgary
	298-6768			
Hydrogeo Canada Inc. - SNC Lavalin	Laurent	Letendre	Directeur de projets	Quebec
	514 866-2601			
ICI Bio Products	Neil	Gray	Team Leader -	Mississauga
	(416) 823-7160			
Imperial Oil Limited	Adrian	Bakker	Environmental Engineer	Calgary
	403-258-8718			
Imperial Oil Limited	Evan	Birchard	Environmental Advisor	Calgary
	237-3902			
Indian & Northern Affairs Canada	Gregory	Hlady	District Technologist -	Sioux Lookout
	807 737-2800			
Industrial Environmental Services Inc.	Frank	Hume	Vice President	Prince George
	604 564-2943			
Integrated Explorations	Al	Melkic	Research Director	Guelph
	(519) 822-2608			

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Company	Name		Title	City
Intera-Environmental Division	Louis 613 226-5442	Sabourin	Project Hydrogeologist	Nepean
Jacques Whitford Environment Limited	Lloyd 506-457-3202	Lemon	Hydrogeologist	Fredericton
Jacques Whitford Environment Limited	Suther 902 468-7777	Yuill	Manager Environmental	Dartmouth
Kananaskis Centre for Environmental Research	R.	Danielson	Professor	Calgary
Keystone Environmental Resources	K. (604) 273-0893	Evans	Senior Project Manager	Richmond
Keystone Environmental Resources	Keith 604-273-0898	Waiz	Jr. Engineer	Richmond
Klohn Leonoff Ltd	Owen 604-273-0311	Quinn	Senior Hydrogeologist	Richmond
Kupchanko & Assoc.	Eugene	Kupchanko	President	West Vancouver
Levelton Associates	Neil (604) 276-1411	Shah	Senior Environmental	Richmond
Lynx Geosystems Inc.	Simon 604 682-5484	Houlding	Director Technical Services	Vancouver
Lynx Geosystems Inc.		Kirkham		
MacLaren Engineers	Edward 416 - 756-3700	Lloyd	Design Engineer Specialist	Willowdale
Macmillan Bloedel	Richard 604 661-8283	Young	Environmental Coordinator	Vancouver
Magnum Oil	Orville	Middleton		Saskatoon
Manitoba Department of Environment	Don 204 945-7094	Labossiere	Environment Officer	Winnipeg

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Company	Name	Title	City
Maritime Groundwater Inc.	John Hart 502 458-1248	President	Fredericton
Metro-Toronto Works Dept.	Ken Hogg 416 392-4226	Chief Engineer-Landfills	Toronto
Ministry of Energy and Resources Quebec	Diane Myrand 418-646-4339	Engineer	Charlesbour
Ministry of Environment Lands & Parks	John Jungen 604 387-9929	Soils Specialist	Victoria
Ministry of Environment Lands & Parks	Coleen Hackinen 604 584-8822	Senior Environmental	Surrey
Ministry of Environment Lands & Parks	Bill Hodge 604 387-9463	Senior Technicial	Victoria
Ministry of Environment Lands & Parks	Mike Wei 604 356-5062	Geological Engineer	Victoria
Ministry of Environment Lands & Parks	Robert Davies (604) 758-3951	Environmental Safety	Nanaimo
Monenco Inc.	John Lambert (604) 737-1166	Head, Environmental	Vancouver
Morrison Hershfield Project Managers Inc.	Franklin Holtforster 613 727-9802	President	Nepean
Morrow Environmental Consultants Inc.	Grant Byers 604 986-1168	Manager	North Vancouver
Morrow Environmental Consultants Inc.	Lyndon Jacklin 986-1168	Hydrogeologist	North Vancouver
National Defence	Don Beamish 604-363-2768	Base Properties Officer	F.M.O. Victoria
National Defence	Ross Gibbs 604-363-4892	Civil Engineer	F.MO. Victoria
National Research Council Canada,	Rejean Samson (514) 496-6180	Group Head, Envir.Eng.	Montreal

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Company	Name		Title	City
New Brunswick Dept. of Environment	Louise	Stewart	Contaminated Site	Fredericton
	506-457-4848			
Newalta Corporation	Claire	McAuley	Sr. Environmental	Calgary
	(403) 266-6556			
Nor-Am Biologicals Inc.	Allan	Cocks	President	Salmon Arm
	604 832-5566			
Nor-Am Biologicals Inc.	Rick	Farrell	Sec./Trea.	Salmon Arm
	604 832-5566			
Norecol Environmental Management Ltd.	Tom	Milner		Vancouver
	(604) 681-1672			
Norecol Environmental Management Ltd.	Della	Berwanger		Vancouver
	(604) 681-1672			
Nova Corporation	Dave	Deyell		Calgary
	290-6638			
Nova Husky Research Corporation	Roy	Jeffries		Calgary
	(403) 250-0631			
O'Connor Associates Environmental Inc.	J.	Neus	P. Eng.	Langley
	604 888-6900			
OHM Corporation	Cris	Jespersen	Project Engineer	Walnut Creek
	(510) 256-7187			
Ontario Hydro	Edwin	Leung	Environment Specialist	North York
	590-2436			
P.W.C. - E.C. Unit - A & ES	Don	Nakrieko	Head Civil Engineering	Calgary
	292-4724			
Paulsen & Associates	Dale	Wilkins		Seattle
	(206) 783-0730			
Payton Knight Ltd. Consulting Engineers	Inder	Singh	Project Engineer	West Vancouver
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PBK Engineering Ltd.	Chris	Gillham	Project Manager	Vancouver
	604-736-5421			

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Company	Name		Title	City
Petro-Canada Inc.	Adolfo	Silva	Sr. Environmental Advisor	Calgary
	296-6085			
Petro-Canada Inc.	Farhad	Seif	Manager Env. Safety &	North York
	416 730-2016			
Petro-Canada Inc.	Al	Stolz	Advisor Env.	Calgary
	(403) 296-3741			
Petro-Canada Inc.	Tom	Eason	Coordinator Env.	Calgary
	(403) 296-6005			
Petro-Canada Products	Rick	Merryfield	Coordinator Environment	Calgary
	(403) 296-6445			
Phillips Petroleum Company	Steve	de Albuquerque	Associate Environmental	Bartlesville
	(918) 661-8785			
Piteau Associates	David	Tiplady	Senior Hydrogeologist	North Vancouver
	604 986-8551			
Piteau Engineering Ltd	Paul	Hardisty	Principal Hydrogeologist	Calgary
	403-286-2522			
Piteau Engineering Ltd.	Paul	Weeks	Hydrogeologist	Calgary
	286-2522			
Piteau Engineering Ltd	Ted	Dabrowski		Calgary
	403-286-2522			
Pottinger Gaherty Environmental Consultants	Will	Gaherty	Vice President	Vancouver
	604 682-3707			
Prairie Biological Research Ltd.	Ram	Mehta	President	Edmonton
	450-3927			
Public Works Canada	Phil	Wong	Pollution Control Engineer	Vancouver
	604 666-5165			
Quantum Environmental Group	Jeffrey	Westeinde	President	Richmond
Regional District of Fraser-Cheam	Robert	Moore	Executive Director	Chilliwack
	604 792-0061			

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Company	Name		Title	City
Remediation Technologies Inc. (Retec)	Grant	Hainsworth	Environmental Eng.	Seattle
	206 624-9349			
Rescan Environmental Services Ltd.	David	Flather	Contaminant Specialist	Vancouver
	604 689-9460			
Robert S. Kerr Environmental Research	John	Matthews	Chief Applications &	Ada
	405-332-8800			
Robert S. Kerr Environmental Research	Steve	Schmelling	Chief Subsurface Systems	Ada
	405-332-8800 (434)qq			
SCS Engineers	Sandra	Whiting	Project Scientist	Bellevue
	206-822-5800			
Seacor Environmental Engineering Inc.	Brian	Stuckert	Senior Engineer	Vancouver
	604 734-5528			
SERVCO Environment Ltd.	Jason	Daniels	Technical Advisor	St. John's
	709 722-9498			
Shell Canada Limited	Randall	Warren	Safety and Environment	Calgary
	403-691-5420			
Shell Canada Limited	David	Hagopian	Senior Staff Process	Calgary
	(403) 691-2514			
Shell Canada Limited	Brian	Goliss	Staff Environmental Tech.	Calgary
	691-3171			
Shell Canada Products Limited	Pilon	Adrien	Advisor Hydrogeolgist	Montreal
	514 287-7262			
Simon Fraser University	Donald	Bryant		North Vancouver
	(604) 929-9112			
Soil Enrichment Systems Inc.	Phil	Lalande	President	Barrie
	708 734-2793			
Soilcon Laboratories Ltd.	Michael	Goldstein	President	Richmond
Solarchem Environmental Systems	Keith	Bircher	V.P. Engineering	Richmond Hill
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Company	Name		Title	City
SRK-Robinson Inc.	Mike 604 985-7176	Eivemark	Senior Geotechnical	North Vancouver
Steffen Robertson & Kirsten (B.C.) inc.	John (604) 681-4196	Chapman	Chemical Engineer	Vancouver
The Corporation of Delta	Jeff (604) 946-3282	Rahn	Assistant Environment	Delta
Thurber Engineering Ltd.	B. (604) 684-4384	Nakai	Manager	Vancouver
Thurber Environmental Consultants Ltd.	David (604) 687-0100	Allen		Vancouver
Thurber Environmental Consultants Ltd.	Ken (403) 253-9217	Manly	Sr. Project Engineer	Calgary
Thurber Environmental Consultants Ltd.	John (403) 438-1460	Graham		Edmonton
Trans Mountain Pipe Line Company Ltd.	J. (604) 739-5258	Horner	Project Manager	Vancouver
Trans Mountain Pipe Line Company Ltd.	Norman (604) 739-5256	Rinne	Pipeline Engineer	Vancouver
TransMountain Pipe Line Company Ltd.	Dan 604 739-5241	O'Rourke	Environmental Engineer	Vancouver
Transport Canada	Robert 604 666-5370	Sisler	Superintendent	Vancouver
Transport Canada, Airports Group	Joseph (403) 495-6056	Belicek	Regional Environmental	Edmonton
Travis Chemicals Inc.	Douglas (403) 263-8660	Farrell	Manager Special Products	Calgary
Travis Chemicals Inc.	James (403) 263-8660	Carlile	Vice President	Calgary
Triton Environmental Consultants Ltd.	Brian 604 279-2093	Guy	Senior Hydrologist	Richmond

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Trow Consulting Engineers Ltd.	Tim	Orpwood	Branch Manager	Surrey
	604-291-0053			
UMA Engineering Ltd.	Tom	Wingrove	Director, Earth Services	Winnipeg
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UMATAC Industrial Processes	Robert	Ritcey	Manager	Calgary
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Universal Dynamics	Mike	Rockandel	Senior Process Engineer	Vancouver
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University of Alberta	Sandra	Kenefick	Research Associate	Edmonton
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University of Alberta	Clara	Qualizza	Graduate Student	Edmonton
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University of Alberta	Murray	Gray	Professor	Edmonton
	(403) 492-5805			
University of Alberta	Desirée	Jens	Student	Edmonton
	(403) 430-0246			
University of Alberta	Abdel	Kharrat	Department of Soil	Edmonton
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University of British Columbia	Dan	Walker	Grad Student	Vancouver
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University of British Columbia	Raghava	Desika	Student	Vancouver
	604 228-0911			
University of British Columbia	Charles	Bulmer	Graduate Student	Vancouver
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University of British Columbia	Mike	Mohtadi	Graduate Student	Vancouver
University of Manitoba	Donald	Shields	Professor of Civil	Winnipeg
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	306 966-8498			

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Company	Name		Title	City
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Vancouver Port Corporation	Darrell 604 666-3170	Desjardin	Environmental Coordinator	Vancouver
Wastewater Technology Centre	Marc 416-336-4696	Halevy	Chemical Engineer	Burlington
Wastewater Technology Centre	Rob 416 336-4689	Booth	Manager Site	Burlington
Wastewater Technology Centre	Craig (416) 336-4691	Wardlaw	Senior Project Engineer	Burlington
Wastewater Technology Centre	Henryk 416-336-4855	Melcer	Manager - Biological	Burlington
Westcoast Energy Inc.	Gordon	McKenzie	Environmental Engineer	Vancouver
Western Research	Jerry 291-1313	Demchuk	Reclamation Specialist	Calgary
Westmar Consultants Inc.	Campbell 604 985-6488	Anderson		North Vancouver
Westmar Consultants Inc.	Fred 604 985-6488	Ciambrelli		North Vancouver
XCG Consultants	Richard 519 741-5774	Rush	Principal	Kitchener

ACRONYMS AND INITIALS FROM
THE 2nd ANNUAL SYMPOSIUM ON GROUNDWATER AND SOIL REMEDIATION
MARCH 25-26, 1992

AERT - Alberta Environmental Research Trust (Canada)
ACP - advanced oxidation processes
AOSTRA - Aberta Oil Sands Technology and Research Authority (Canada)
APEG - alkaline (A) solution of potassium hydroxide and polyethylene glucol (PEG)
ASGP - Alberta Sour Gas Plants
BEST^{R} - Basic Extraction Sludge Treatment
BETO - Burlington Environmental Technology Office (Canada)
BETX - benzene, ethylbenzene, toluene, xylene
BTEX - benzene, toluene, ethylbenzene and xylene
CBC - circulatory bed conductor
CCME - Canadian Council of Ministers of the Environment
CCREM - Canadian Council of Resource and Environment Ministers (now CCME)
CF - crutical fluid
CPA - Canadian Petroleum Association
CPA/ERAC - Canadian Petroleum Association/Environmental Research Advisory Council
CPPI - Canadian Petroleum Products Institute
CSMoS - Center for Subsurface Modeling Support (U.S.)
DAF's - dilution/attenuation factors
DEA - diethanolamine
DESRT - Development and Demonstration of Site Remediation Technologies(Canada)
DND - Department of National Defense (Canada)
DNAPL - dense non-aqueous phase liquids
D.O. - dissolved oxygen
DRE - destruction and removal efficiencies
ECAO - Environmental Criteria and Assessment Office (U.S.)
E&P - exploration and production
EETD - Environmental Emergencies Technology Division (Canada)
EMSL - Environmental Monitoring Systems Laboratory (U.S.)
EPA - Environmental Protection Agency (U.S.)
ERL - Environmental Research Laboratory (U.S.)

ERT - Environment Response Team (U.S.)

GASReP - Groundwater and Soil Remediation Program (Canada)

GC/MS - gas chromatography/mass spectrometry

GC/PID - gas chromatography/photo ionization detection

GEMS - Genetically Engineered Microorganisms

GIS - Geographical information system

HELP - Help End Landfill Pollution

IGWMC - International Ground Water Modeling Center (U.S.)

LAH - light aliphatic hydrocarbon

LBL - Lawrence Berkeley Laboratory (U.S.)

LNAPL - Light non-aqueous phase liquid

MTBE - methyl tertiary butyl ether

NAPL - Non-aqueous phase liquid

NCGWR - National Center for Groundwater Research (U.S.)

NCSRP - National Contaminated Site Remediation Program

NCSU - North Carolina State University

NIOSH - National Institute for OccupationalSafety and Health (U.S.)

OSWER - Office of Solid Waste and Emergency Response (U.S.)

ORD - Office of Research and Development (U.S.)

OSC - on scene coordinators (U.S.)

PAHs - polyaromatic hydrocarbons or polynuclear aromatic hydrocarbons or polycyclic aromatic hydrocarbons

PCE - tetrachloroethylene

PCP - peutachlorophenol

PNA's - polynuclear aromatics

PRDF - Petroleum Release Decision Framework

QA/QC - Quality Assurance/Quality Control

RAGS - Risk Assessment Guidance for Superfund (U.S.)

R,D & D - research, development and demonstration

ROD - Record of Decision (U.S.)

RPM - Regional Remedial Project Managers (U.S.)

RREL - Risk Reduction Engineering Laboratory (U.S.)

RSKERL - Robert S. Kerr Environmental Research Laboratory (U.S.)

SAF - sludged addition factor

SCAMP - Subsurface Cleanup and Mobilization Processes (U.S.)

SFE - supercritical fluid extraction

SRIC - Subsurface Remediation Information Centre (U.S.)
SRT - Subsurface Remediation Technology (U.S.)
SVE - soil vapour extraction or soil vacuum extraction
SVVS^{TM} - Subsurface Volatilization and Ventilation System
SWEP - BC Special Waste Extraction Procedure (Canada)
TCE - trichloroethylene
TCLP - Toxicity Characteristic Leaching Procedure
TKN - total Kjeldahl nitrogen
TOX - total organic halogen
TSC - Technology Support Centres (U.S.)
TSCA - Toxic Substances Control Act (U.S.)
TSP - Technical Support Project (U.S.)
TST - Technology Support Core Team (U.S.)
TEH - total extractable hydrocarbon
UST - underground storage tank
UVB - Vacuum Vaporizer Well
UW - University of Waterloo (Canada)
VCR - Valorization of Chlorinated Residues
VOA - volatile organic analysis
VOC - volatile organic compound
WHC - water holding capacity
WHMIS - Workplace Hazardous Materials Information Systems (Canada)
WTC - Wastewater Technology Centre (Canada)